

The Impact of Emerging Technologies on Future Air Capabilities

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DSTO-GD-0186

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ABSTRACT

This study aims to assess technology developments to 2025, and how they may impact on future air capabilities, in order to better inform Air Force long range planning activities. A number of US studies address similar issues; with one assessing the impact in the context of an 'alternate futures' approach and the development of a value model. The generic Air Force capabilities of Awareness, Reach, Power and Support are used in this study to assess potential impacts of technological developments.

RELEASE LIMITATION

Approved for public release



Published by

*DSTO Aeronautical and Maritime Research Laboratory
PO Box 4331
Melbourne Victoria 3001 Australia*

*Telephone: (03) 9626 7000
Fax: (03) 9626 7999
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AR-010-594
December 1999*

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Executive Summary

This study aims to assess technology developments to 2025, and how they may impact on future air capabilities, in order to better inform Air Force long range planning activities. A number of US studies address similar issues; with one assessing the impact in the context of an 'alternate futures' approach and the development of a value model. The generic Air Force capabilities of *Awareness*, *Reach*, *Power* and *Support* are used in this study to assess potential impacts of technological developments.

Technology trends and their rate of advance are influenced by many drivers including: cost, commercial imperatives, military requirements, capabilities, integration, leverage, environmental issues and public sentiment.

Technological developments with potential to impact on future Air Force capabilities include: computing power, communications, microelectro-mechanical systems (MEMS), nanotechnologies, uninhabited air vehicles (UAV), hypersonic systems, artificial intelligence, human factors, energy weapons (including laser and electromagnetic pulse), sensors, materials, simulation and modelling.

Sensors may move from single to multi-mode, as well as multi- and hyper- spectral systems. Application of composite and metal matrix materials may become more common, with emphasis on lower cost, lightweight, strength, heat and damage tolerance and 'smart' materials possessing self- monitoring and healing capabilities.

The application of a technology requires considerable foresight and often the concomitant development of other technologies. The world wide web, which is revolutionising the way we communicate information, uses known and relatively mature computing and communications technologies.

For *Awareness*, high capacity communications systems could be based on lasers, millimetre wave, high capacity fibre lines and satellites. Developments in millimetre wave sensors, laser radars, synthetic aperture radars (SAR), focal plane arrays (FPA), multimode as well as multi- and hyper- spectral sensors, artificial intelligence and data fusion technologies could, together with communications and countermeasures technologies, contribute to timely and high confidence situation awareness.

Major technology influences on *Reach* capability include propulsion systems emphasising higher power to weight ratios, faster and stealthy (including missiles) airframes, lighter and stronger airframe materials and incorporating smart sensors with adaptive and self-healing capabilities. Reach systems include aircraft, UAVs and spacecraft. Increasing emphasis on air breathing ramjet and scramjet technologies would enhance *Reach* capability.

More accurate missiles with tunable high energy density explosives, and with hybrid and hypersonic propulsion systems would contribute to *Power* capability. Such high speed systems could have stand-off ranges in the order of 750 nmiles and incorporate multi-mode and imaging seekers. Overall, in weapon system technology the emphasis may move from the delivery platform to the missile possessing greater speed, stealth, an integrated seeker system and stand-off range.

Developments will continue in directed energy weapons, such as high energy laser systems and electromagnetic pulse, with fielded systems available in the short to medium term. High energy laser systems designed initially for theatre ballistic missile defence may operate at ranges greater than 400 km from its target.

Uninhabited combat air vehicles (UCAV) would be capable of high maneuverability and employ small high performance missiles in the combat role. Estimated lower operating and support costs, compared to manned aircraft, would lead to savings over the lifetime of the aircraft.

Countermeasure capabilities will be drawn from a number of technologies including computing, laser, signal processing, information systems and stealth.

Support capabilities may be enhanced by advances in training, emphasising immersive environments and tailored training regimes. A consideration of human factors will be a key part of capability planning, with the human and machine viewed as an integrated entity. Direct voice input and eye movement control techniques may be adopted in the short term, while EEG techniques, allowing a 'think-shoot' capability, may be feasible in the longer term.

Simulation technologies continue to develop and may include synthetic environments incorporating computer generated forces.

Smart self monitoring and healing systems would allow the adoption of a replacement for cause philosophy, leading to greater system availability and reduced support costs.

Technological developments will have significant implications for air Force planning activities, and embrace areas of command and control, operations, simulation and training, logistics and acquisition.

Concepts such as information warfare, network centric warfare and command and control would be enabled by the synergistic application of a variety of technological advances.

Technological developments should be revisited regularly to assess trends as well as the robustness of the futures planning methodology being applied.

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1. Introduction

1.1 Aim

1.1.1. The aim of the study is to assess technology developments which may impact on air capabilities to the year 2025, to better inform the Air Force long range planning process.

1.2 Background

1.2.1. The use of advanced technology is a key part of Australia's defence strategy (1) (2). The effective application of this technology is of critical importance, which needs to be addressed in the context of defence planning. Guidance relating to research and development support for the application of advanced technologies in the context of Australian defence, is articulated in a recent paper (3), while another paper aims to inform decision makers on technological advances with potential defence application and S&T resource implications (4).

1.2.2. Recognising longer term trends in technological developments, and their potential impact and application presents another challenge. The rapid advances in technology means that information to planners has to be constantly upgraded and updated. Recognition of this by the USAF, resulted in two recent major 'forecasting' studies (5) (6).

1.2.3. In addition, over the next 25 years aspects such as the evolution of regional military capabilities, alliances, force structure, command and control, and geopolitical environments, as well as technological developments, will present challenges for ADF and RAAF management, structures and planning. Changes in military thinking and doctrinal developments, spurred in part by technological advances, is acknowledged in concepts such as the Revolution in Military Affairs (RMA). On this basis, a true revolution in military affairs is believed to occur when the three components of new technology, changes in doctrinal concepts and changes in the organisation of military structures occur simultaneously (7).

1.2.4. Air Force Headquarters is setting in train initiatives to address how these and other aspects may impact on long range planning. As part of the initiative, this study sets out to assess technological developments and their potential impact on future Air Force capabilities. The study is similar in concept to that undertaken by DSTO in 1995 to support Army in the context of planning for the 21st century (8).

2. The 2025 Challenge

2.1 Challenge

2.1.1. Long term planning is carried out in the context of a future world shaped by a number of influences. These influences include military, geopolitical, environmental, technological and social. They may be global or local in nature, may change rapidly and lead to both evolutionary and revolutionary outcomes. The vast array of interacting influences, both known and unknown, which shape the future world, makes for a high degree of uncertainty.

2.1.2. Thus the challenge is to forecast the future in a meaningful way, to allow scope for a range of influences, so that a broad rather than narrow focus is adopted, resulting in a number of 'alternate futures'.

2.1.3. An additional challenge is not to adopt the US view of the world and the potential impact of emerging technologies. It is important to note, that while scientific and technological research may be universal or global in nature, its application and influence across different global regions is not. Thus, while this study makes frequent reference to major US studies (5) (6) it does not merely accept the US viewpoint on future developments and their impact on force capability, since Australia's outlook and subsequent requirements differ considerably from those of the US.

2.2 Forecasting Approaches

2.2.1. Forecasting technological developments must be done outside the constraints of present day thinking and to allow for revolutionary as well as evolutionary changes, so that a mere linear or incremental view from the present to the future is not presented as the only way ahead. Past 'forecasting' experience has shown, that while there is a tendency to overestimate short term, there is a tendency to underestimate long term, technological developments and impacts.

2.2.2. An approach used elsewhere is to adopt the concept of *foresight* rather than *forecast*. This broader term does not constrain viewpoints, and offers future perceptions rather than absolute predictions (9).

2.2.3. Forecasting technological change, and its impacts is risky, since unexpected scientific or technological breakthroughs may occur at any time. In general, most predictions for technological innovations have been overinflated. One notable exception to this is the growth of the computing industry, where forecasts have tended to underestimate actual growth. Even IBM predicted, in 1980, that the world market for personal computers in the early 1990s would be 275 000, while the actual number is about 60 million.

2.2.4. The impact of a technology on future operations may be assessed by employing a bottom-up approach, which is similar to that used in *Air Force 2025* (10). The bottom-up philosophy does not demand pre-requisite assessments on strategic directions, future operational concepts or Air Force doctrinal issues. It tends to be free from institutional biases and pre-conceived ideas. This study uses such an approach.

2.2.5. The trap of providing technological solutions rather than addressing capability requirements is avoided. An outcome is that the extremes of 'requirements pull versus technology push' are not adopted, so that a technology may broadly influence a capability and its development, but is not defined as a 'requirement'.

2.2.6. Some technologies may provide greater capability leverage than others, in that they offer high capability for relatively low risk. The risks may be assessed under headings of technology, cost and time. It is important to be able to identify such high-leveraged technologies, particularly in the context of cost effectiveness.

2.2.7. Thus, the acceptance of risk in developing a technology is directly related to the capability or value that success offers. This is shown graphically in figure 1. The aim is for any set of technology/value coordinates to lie above the 'Effectiveness' line in the figure. The 'Effectiveness' line is determined in an arbitrary fashion, using input from a number of sources, including experts in technology fields and end-users.

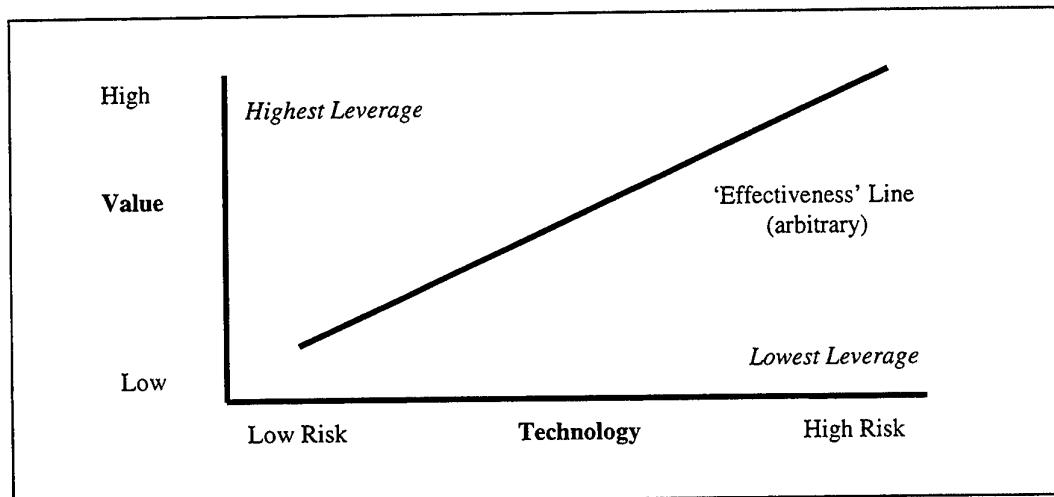


Figure 1: Technology versus value diagram.

2.2.8. An inherent characteristic of long range forecasting, is that potential impacts of technological developments have to be assessed using qualitative rather than quantitative measures. In addition, assessments of future technology developments are based on increasingly 'soft' data the further one attempts to look into the future. Thus, in this study, a 'measure' of capability improvement provided by advances in technology is described in broad, rather than in detailed numerical, terms.

2.3 Alternate Futures

2.3.1. The growth of technological innovation and application will be influenced by a number of factors, while technological developments in turn will be a major factor in determining the future. These issues are addressed in a major US approach to planning called 'Alternate Futures'.

2.3.2. The *Alternate Futures* approach, defined in the USAF study, *Air Force 2025* (6), develops a number of plausible futures to the year 2025, which are determined by consideration of a number of major influences or drivers.

2.3.3. the most important influences or drivers in *Air Force 2025* include:

- Growth and proliferation of technology,
- American willingness and capability to interact with the rest of the world, and
- The generation, transmission, distribution and control of economic, political and military power throughout the world.

2.3.4. In addition, each driver exhibits two extremes, so that technology growth and proliferation ranges from 'constrained' to 'exponential', the American world view ranges from 'domestic' to 'global', and power distribution ranges from 'concentrated' to 'dispersed'.

2.3.5. This gives rise to eight 'extreme' alternate futures occupying the corners of the alternate futures space, and delineating its boundaries. All other 'alternate futures' are contained within this space, and the approach is designed to ensure that planning will be well informed and without surprises, regardless of what vision of the future becomes reality.

2.3.6. Consideration of the alternate futures leads to the development of a number of system concepts and technologies to satisfy US Air Force required capabilities. However, not all system concepts nor their enabling technologies can be developed. Thus, the relative importance of both the system concepts and the enabling technologies had to be prioritised. For the Air Force 2025 study this was accomplished via the development of a value model called '*Foundations 2025*' (11).

2.3.7. For Australia, Air Force is adopting the 'alternate futures' as one approach for future planning. Air Force Headquarters is establishing a futures planning team which aims to develop a set of futures, using both indigenous and global inputs. The challenge of the *Emerging Technologies Study* is to feed into the process by addressing issues relating to technological developments and, as a key driver, their potential impact on future activities. It is important to note that while the *Alternate Futures* process is developed in the US, the focus and major outcomes must be firmly based on Australian interests, drivers and planning imperatives. It is also worth noting that alternate postulated futures will have 'varying' access to different technologies, so that the material presented in this paper will have to be filtered through other alternate futures characteristics.

2.4 Air Force Generic Capabilities

2.4.1. In this study, the potential impact of a technology is addressed in the context of four generic capabilities:

- Awareness
- Reach
- Power
- Support

2.4.2. These capabilities are generic in the sense that they are not constrained by current guidance or operational concepts, and so may be broadly applied when considering future Air Force activities. It is believed that these capabilities encapsulate all Air Force activities in meeting its mission, independently of the time-frame (past, present or future) under consideration. It is important to realise that while these capabilities will not differ significantly from the present day, the means by which they are accomplished in the future, will vary substantially.

2.4.3. For each *Capability*, a set of *Force Characteristics* is defined, which describe the distinctive qualities of a capability. Thus, the impact of a technology on a capability may be assessed using measures set against the force characteristics. The relationship between mission, capability and force characteristic is shown in figure 2.

2.4.4. Key technology drivers plus an overview and trends are provided in Sections 3 and 4. Sections 5 and 6 describe plausible future technologies and their applications, based on expert opinion from DSTO and input from other sources (e.g. References 5 and 6).

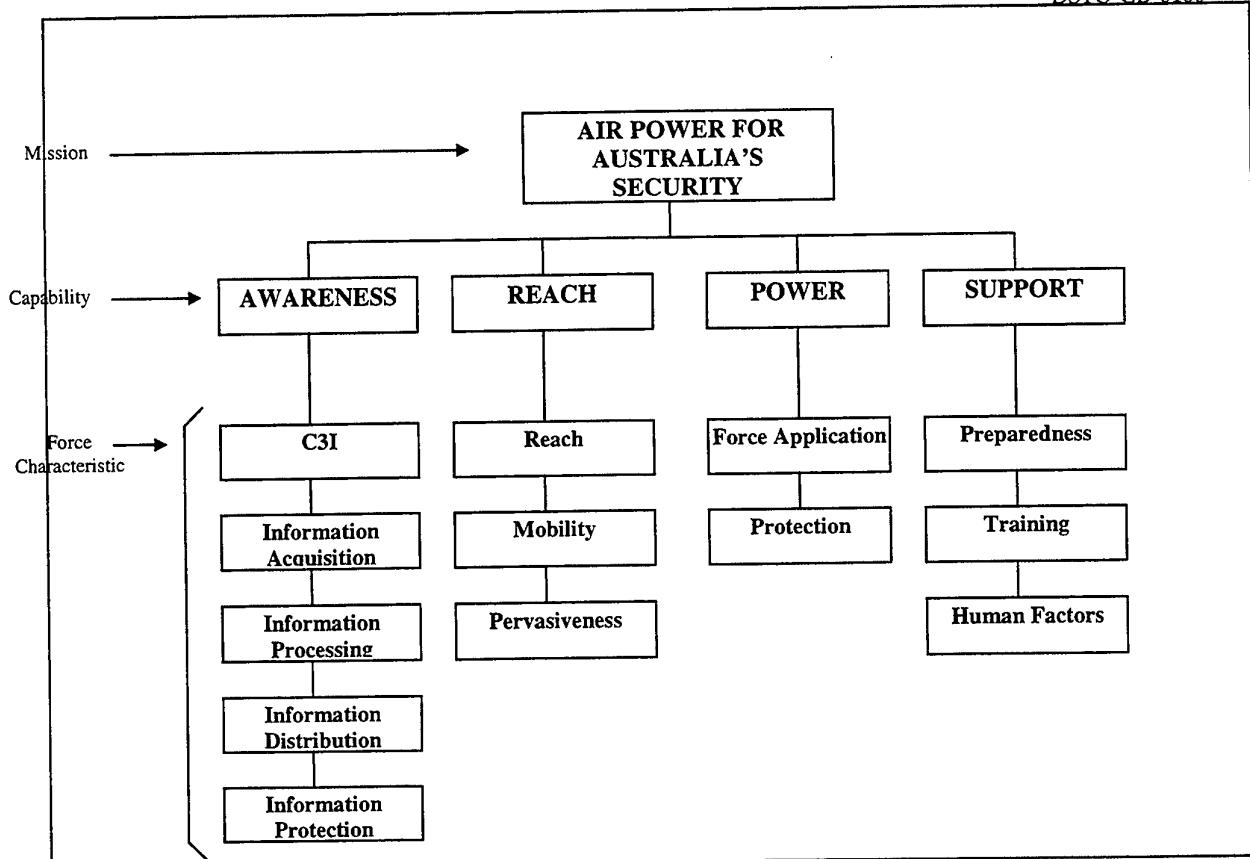


Figure 2: *Mission, Capabilities and Force Characteristics.*

3. Key Technology Drivers

3.1 Drivers

3.1.1. The direction and pace of technological development will in turn be influenced by a number of drivers. The drivers may be constant, immediate or long term, leading to differences in both the rate and extent of development of the technology, and consequently its impact.

3.1.2. Drivers, with examples of contributing factors or technologies in parenthesis, may include the following:

- commercial imperatives both global and local (computing, communication, data links, information technology)
- military requirements, including capability 'voids', at global and local levels (stealth, signatures, platforms including UAVs, seeker, sensor, communication, data links, countermeasures, high energy lasers)
- high-leverage, e.g. recognition of information as a force multiplier
- public sentiment (UAV, non-lethal weapons, precision munitions, hazard mitigation, operational safety, effectiveness)
- environmental imperatives: protection and preservation ('green' technologies)
- systems integration (integration, human factors, modelling and simulation, concept demonstrators)

- capability edge in regional context (operational analysis, modelling and simulation, human factors, information creation and distribution)
- move to operate in space as well as in air (satellite, propulsion, minaturisation)
- cost in addition to capability (high leverage technologies, minaturisation, reusability, commercial-off-the-shelf (COTS), modelling and simulation, cost effectiveness)
- reduced life-cycle costs
- support of force in being (materials, structural integrity, advanced repair technologies, smart materials, systems and materials self-monitoring and healing)
- supportability (training)
- interoperability (standardisation)
- dual- and multi- use capabilities (microchips, nanotechnologies)
- development of niche markets
- non-proliferation (nuclear, biological weapons, chemical weapons)
- revolutionary versus evolutionary philosophy.

3.2 Rate of Advance

3.2.1. The differential rate of advance in technologies is an important factor when addressing potential impacts of those technologies. Thus, the main drivers for a particular technology have to be recognised. Differential rates of advancement are clearly evident in computing, communications and information technologies on the one hand and stealth technologies on the other. While the former is driven mainly by commercial imperatives and is still not considered a mature technology, the latter is driven more by military capability demands and is considered a more mature technology. Currently, exponential growth appears to be associated with commercial, rather than military, driven technologies. However, this situation could reverse in a 'future' involving economic collapse and the growth of military factions.

3.2.2. It should also be recognised that drivers may not have a universal 'degree' of impact; so that a key driver for advancement of technologies in a US context may not necessarily have the same impact in an Australian context.

4. Technology Overview and Trends

4.1 Introduction

4.1.1. Technologies will continue to develop with time, albeit at varying rates of growth, and influenced by 'drivers' such as those described in Section 3 above. It is noteworthy that capability advances often result from a revolution in thinking rather than a revolution in technology. Such 'thinking' may lead to new concepts, better integration and more effective application of technology (12). Technologies with potential to impact on future air force capabilities are emphasised in this section.

4.1.2. Advances in technology occur across all scientific disciplines, and may result from pure research or be driven by some practical demand or applied goal. Often, there is no obvious potential application of a technology. For instance, many present day applications of laser technology were not envisioned by those carrying out the original research.

4.1.3. On the other hand, advances afforded by technology have in some cases not been fully utilised in the short to medium term, owing to a lack of demand or a perception that the existing technology was sufficient to meet demands. This is shown by the fact that in the early 1990s U.S. telecommunications companies cited an apparent excess of communications capacity to justify cuts to research in the fiber communications field (13). Thus, there may be a considerable time, often in the order of 20 - 30 years, for a technology to move through the stages of *appealing, promising, feasible* and *introduction of capability*. Clearly then, while there is uncertainty regarding future technological developments, there may be even less certainty regarding its application.

4.2 Computing

4.2.1. Computer processing speed has experienced exponential growth rates over the past thirty years, as shown in Figure 3. Owing to rapid advances in microchip technology, there is a doubling of processor speed about every 18 months, according to 'Moore's Law'¹. Indications are that the this growth rate is accelerating, with originally predicted end of century microprocessor capacities now available. However, one estimate is that further growth, based on silicon chip technology, will be limited beyond about 2006, leading to the adoption of alternate technologies such as quantum, molecular and optical computing methods (14) (15). It should be noted that computer speed is more accurately represented in terms of the number of floating operations per second (FLOPS). Current supercomputers run at Gigaflop speeds (16).

4.2.2. Optical computing would provide much higher computing speeds. Developments have centered on devices such as VCSELs (Vertical Cavity Surface-Emitting Lasers) for data input, SLMs (Spatial Light Modulators) for putting information on light beams and high speed APDs (Avalanche Photo-Diodes) for data output. More work remains before digital optical computers will be available commercially.

4.2.3. Accuracy is a major issue with optical computers, so that the devices have practical limits in basic operations. In the near term, optical computers will most likely be a hybrid of optical and electronic systems

4.2.4. A quantum computer would store information, not as strings of ones and zeros as in a 'classical' computer, but as a series of quantum mechanical states. Quantum physics allows particles to be in more than one state at a time, so that it is possible for a particle in a quantum computer to hold more than one bit of information, referred to as a 'qubit'. The quantum computer would allow very fast parallel computing capability. (17)

4.2.5. A functional quantum computer is still beyond the grasp of current technology, and many obstacles must be overcome before a usable computer can be built. A major problem is that slight outside disruption, e.g. heat or light, will cause a system to lose its quantum coherence, while the very process of retrieving results would also upset the coherence.

4.2.6. Computing based on biological function, could yield many orders of magnitude improvements in computational capacity, for only a fraction of the energy requirements of current computers (18).

4.2.7. Data storage media will need to improve to keep pace with computer processing power, and may be achieved via optical disk technologies and applications of parallelism (15). Promising areas involve the use of holographic memory, offering 64 billion bits storage capacity on a laser activated crystal the size of a compact disk (18).

¹ Attributed to Gordon Moore, co-founder of Intel.

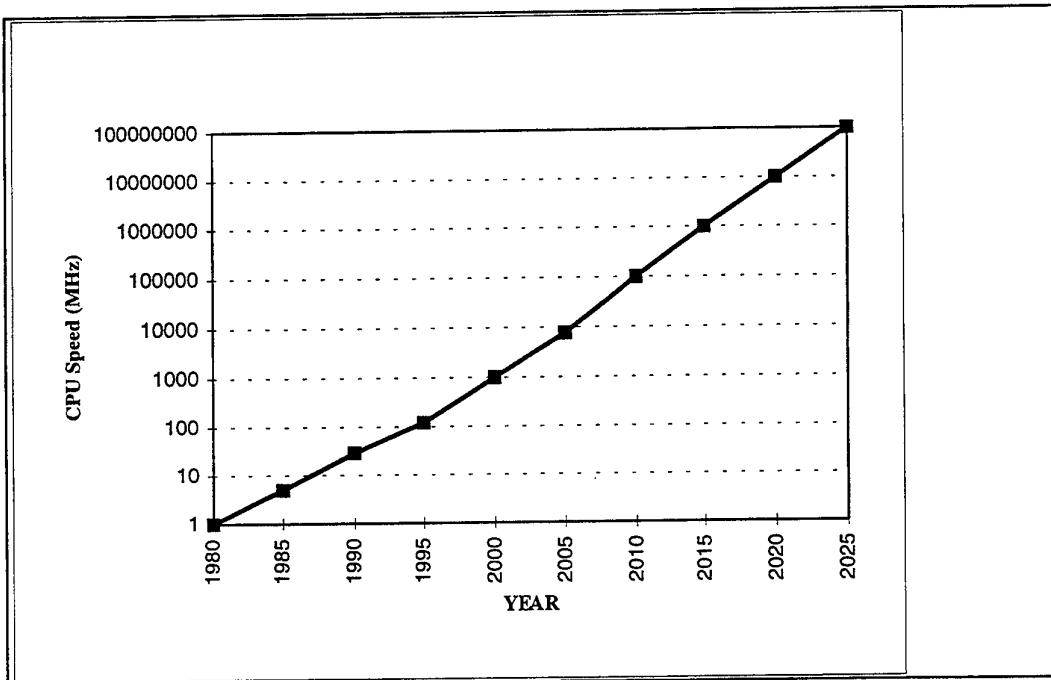


Figure 3: Growth in CPU Speed over time.

4.3 Communications

4.3.1. Communication system bandwidth is a major factor in determining the rate of information and data transfer. Bandwidth is set to grow rapidly, believed in some quarters (19) to outstrip the rate of growth in computer processing power by up to a factor of 10, and driven by commercial imperatives, such as the requirement of video-on-demand, and increasing reliance on optic fiber over copper wire as the means of transmission. This is shown by the fact that commercial transmission rates, using optic fibers, have grown from 2.4 gigabits per second in 1994 to 10 gigabits per sec in 1995 and to 40 gigabits per second in 1997 (19), and may reach a capacity of one terabit per second over a single fiber in the near future (20). The full potential of fiber optic communications can only be realised once systems become truly 'photonic'.

4.3.2. Currently, in fiber networks a signal has to be converted to electronic format for processing in order to amplify, switch, insert or remove a pulse. This optoelectronic conversion limits the system, but advanced techniques such as an optical amplifier, which uses fiber embedded erbium ions shows promise. Such an amplifier, unlike its electronic counterpart, allows transmission speeds greater than 50 gigabits per second, and can boost the power of many wavelengths simultaneously. However, optic fibers offer the potential of terabit transmission rates. This is set in context by the fact that high resolution television images require about a gigabit per second of bandwidth, if the data are not compressed (13).

4.3.3. Generally then, communications may be via photonic rather than electronic means. Such developments, together with increasing use of advanced communications technologies such as asynchronous transfer mode (ATM) would yield virtually unlimited bandwidth. ATM uses cells of a given length, and provides efficient transmission of voice, video and data all at once.

4.3.4. The development of Digital Signal Processors (DSP) is of critical importance, since they are communications equivalent of a computer's microprocessor. DSP capacities have accelerated at three times the rate of microprocessors over the recent past (19).

4.3.5. Military security requirements may temper communications capacity somewhat, since there is a tradeoff between high bandwidth and security. The latter requires redundancy and error correction data, which use up some of the available bandwidth. However, fiber optic cable is inherently more difficult to 'tap' undetected, thus providing an additional driver for this technology.

4.3.6. Commercial satellites will provide communications outside the fiber networks. For instance, TELEDESIC, a proposed LEO based global communications satellite system comprises 288 satellites occupying 12 orbital planes. The satellites would orbit at an altitude of 1350 km and incorporate ATM switching. This high capacity system, planned for early in the next decade, would be used predominantly for data transmission (21).

4.3.7. Commercial satellite based systems may give an adversary access to information on force disposition in a potential conflict. However, the systems global nature and built-in redundancy ensures at least operational assurance, whilst other measures may be taken to render useless any information intercepted by the adversary (20).

4.3.8. Laser communications would offer high bandwidth capability between platforms, and could be part of a multi-function system that incorporates laser weapon, laser countermeasures and communications capability in one entity.

4.3.9. Continuous growth in information availability and access is demonstrated by the fact that in 1995 the Internet grew by 10% per month throughout the year, while the World Wide Web grew at a rate of 10% per week (22). The next generation Internet may be capable of 100 Gbit/sec backbone transmission rates, compared to current networks operating at 1.5 Gbit/sec backbone transmission (23).

4.3.10. The number of Internet users has grown from 1.12 million in January 1990 to 57 million in January 1996, and is set to reach 707 million by early 2000 at this rate of growth (24). This demonstrates further the divide between communications and information rich and poor societies, given that over half the World's population have never made a telephone call.

4.4 Monolithic Microwave Integrated Circuits (MMIC)

4.4.1. These gallium arsenide (GaAs) circuits provide high power amplification, allied with relatively low space and weight requirements. MMICs incur a cost penalty, but this is expected to decrease as the technology matures and their application becomes more routine (25).

4.4.2. MMICs may be considered a high leverage technology, owing, for example, to their capability to extend the range and power of radars and to enable the application of millimeter wave sensors, together with their low weight and space requirements. Millimeter wave communications and sensor applications offer high bandwidth capacity for the former and high resolution for the latter, in the context of small and lightweight systems (26).

4.5 Microelectromechanical Systems (MEMS)

4.5.1. MEMS integrates mechanical, optical and other functions along with microelectronics on a single chip. Developments in MEMS technology allows miniaturisation where transducers, actuators, control electronics and signal processing reside on a single chip. This may lead to applications such as microsensors for

surveillance and reconnaissance, embedded sensors in platform systems, microactuators for aligning imaging systems and microjets for turbulence control in airframes (27). It may be possible to integrate many of these applications into larger systems, offering possibilities of self monitoring (smart) structures, adaptability and autonomous control (28).

4.5.2. The miniaturisation of sensors, such as chemical and optical, would allow the deployment of large numbers of miniature sensors on very small platforms such as micro-UAVs, to provide data on activities. System survivability is enhanced by large numbers offering 'multiple-redundancies' and the low signatures offered by the micro systems.

4.6 Power Systems

4.6.1. The efficiency of photovoltaic electrical power systems continues to increase from 14% (Silicon based cells) in 1980, to greater than 18% (Gallium Arsenide GaAs based cells) in early 1990s and currently 23% (Gallium Indium Phosphide/Gallium Arsenide based cells) (29)². Efficiencies approaching 50% may be possible by discovering semiconductor materials capable of generating more than one electron per photon (30). Decreasing cost, as evidenced by a 40 fold decrease in the cost of generating photovoltaic power in the period 1979 to 1989, together with greater efficiency, would make this type of power generation economically competitive over the next 20 years (20).

4.6.2. Battery technology, driven by commercial imperatives such as the development of electric motor cars, is rapidly advancing. Current lead - acid and nickle - cadmium based batteries have low energy densities (less than 100 W.hr/kg). In the medium term this may be improved by batteries based on nickle - metal hydride, offering energy densities of 175 W.hr/kg, while in the longer term lithium/solid polymer electrolyte/intercalation cathode (Li/SPE/IC) batteries show promise, with energy densities in the range 250 - 400 W.hr/kg. However, application of the latter system is long term since issues such as low power densities and poor cycling characteristics have to be addressed (31).

4.6.3. Fuel cell technologies will continue to develop. They offer the prospect of 40 - 70% efficiencies, low pollution levels and may use fuels such as natural gas, coal derived gas, biogas, alcohols, diesel and jet kerosine, to provide power in an electrochemical process. Most current research is aimed at providing power for municipal or commercial applications on a relatively large scale. Technologies under active consideration include molten carbonate, solid oxide, polymer electrolyte systems and the phosphoric acid fuel cell; with the latter now entering the commercial marketplace. The main challenge to commercialising a fuel cell technology appears to be the competing technology of combustion turbines, where advances in aero-derivative combustion turbines provide for efficient municipal power generation (32).

4.6.4. Overall there may be an increasing emphasis on deriving energy from the environment. This would include not only advances in solar and wind power generators, but also might involve using enzymes whereby a system would derive energy by 'consuming' organic matter in its environment. This becomes more feasible as a system's power requirements are reduced by advances in technology. For example, a small unattended ground sensor (UGS) might be able to operate indefinitely by having its meager power requirements provided by some insignificant sources (23).

4.7 Propulsion

4.7.1. A key parameter in propulsion technology is power to weight ratio. The last great advance in this was in the 1940s, when the turbojet was introduced to take over from the

² Figures based on a solar constant limited for a system in Earth orbit of 1.4 kW/m²

traditional internal combustion engine. The turbojet was simpler, lighter and offered a significant increase in the power to weight ratio.

4.7.2. Improvements continue, with modern turbofans and turboprop propulsion systems offering even greater efficiencies. These improvements are due more to better materials, offering higher temperature tolerance, rather than any inherent design characteristics. As a result, higher combustion temperatures are achievable, giving greater thermodynamic efficiency and lower specific fuel consumption (33).

4.7.3. Increases in engine efficiency means that turbine compressor and combustor temperatures are greater than before. New engine materials offering light weight and high stiffness as well as temperature tolerance, such as 'intermetallics' and metal-matrix composites would improve performance. Other developments such as a single fluid for both propulsion and lubrication may add to the efficiency of future propulsion systems (34).

4.7.4. Initiatives, such as the integrated high performance turbine engine technology (IHPTET) program aims for a 100% increase in engine thrust to weight ratio, as well as a 35% decrease in production and maintenance costs (35). This program was started in 1988 with the goal of providing these outcomes in its 10 - 15 year lifespan.

4.7.5. There is increasing interest in developing hypersonic air breathing vehicles. Hypersonic flight starts at Mach 4 - 5, and the transition from ramjet (subsonic combustor) to scramjet (supersonic combustor) operation occurs in a range around Mach 6. Above Mach 6, freestream air decelerated to subsonic speeds is so hot (above 1920 C) that combustion products dissociate; an endothermic process leading to heat absorption. On the other hand, the airflow is decelerated to a lesser extent in scramjets, with the result that the 'decelerating' heating effect is substantially reduced (36). Major challenges for developing feasible air breathing hypersonic engines are:

- to completely burn fuel in an engine of reasonable length and weight, with the least impediment to fuel flow, and
- to make an inlet efficient and capable of operating over a range of Mach numbers. (36)

4.7.6. Both the USAF (Hy-Tech project) and DARPA are developing programs to demonstrate a Mach 6 - 8 missile, while NASA is developing concepts for a Mach zero-to-orbit platform, employing a propulsion system consisting of ducted rocket, ramjet, scramjet and finally a rocket, with a main aim to reduce launch costs in a 2025 era spacecraft (36) (37).

4.7.7. Nearer term, one NASA concept is to develop a generic Hyper-X Mach 5 - 10 scramjet, with the ultimate aim of developing a hypersonic cruise aircraft capable of global range (36).

4.7.8. Fuels for propulsion systems, in general underwent little development over the past 40 years, with turbine fuels based on known hydrocarbons such as kerosene remaining virtually unchanged. Now there is increasing emphasis on fuel developments, such as heat-sink fuels, endothermic fuels and chemically reacting fuels. Desirable results from such developments are fuels offering reduced fouling, reduced engine maintenance, reduced emissions, reduced engine signature and increased component life (34).

4.7.9. Endothermic fuels absorb heat to release hydrogen and an olefin. Hydrogen has a higher energy content than hydrocarbons, thus making endothermic fuels suitable for propulsion up to Mach 10. These fuels are doubly attractive for hypersonic propulsion since they perform a structural cooling function in addition to having the higher energy content attributable to hydrogen. Endothermic fuels are also dense and unlike cryogenic fuels can be stored at normal temperatures (37).

4.7.10. Rocket and missile propellants have also changed little over the past 20 years. These continue to be based on propellant fuel and oxidiser technology, though with greater emphasis on liquid hydrogen as a fuel. Solid propellants are still based on aluminium and hydrocarbon polymers as fuels with perchlorate or dinitramide oxidisers. Higher specific impulse propellants are required to improve performance and reduce costs (34).

4.7.11. Hydrogen powered air breathing propulsion systems ultimately could be applied to vehicles ranging from aircraft to reusable space launchers. Such systems have a potential payload or range advantage over completely rocket powered systems since oxygen is not carried for combustion (38).

4.7.12. Environmental factors, such as chemical and heat pollution mitigation, are key drivers for both turbine and rocket fuel developments.

4.8 Platforms

4.8.1. Hypersonic 'waverider' platforms, powered by scramjets, capable of speeds in excess of Mach 10 and designed to 'surf' the high pressure field generated by their bow shocks, may become feasible. The system, based on the experimental LoFLYTE subscale prototype, may use neural network fly by wire controls. Currently, adequate low speed (subsonic) performance remains a problem (39).

4.8.2. A hypersonic space vehicle, or spaceplane, can reach any point on the Earth's surface within tens of minutes. This would make it very difficult to intercept, a key driver for hypersonic research, since it also offsets any technological developments that might defeat or degrade stealth in the medium term.

4.8.3. Spaceplanes would share technology (chiefly propulsion and heat tolerant materials) and operational philosophy with some atmospheric vehicles, including.

- highly supersonic vehicles (M 4 - 6)
- hypersonic air breathing vehicles (M 8 to M 10 -12), and
- transatmospheric vehicles (TAV) which operate between the upper air breathing and sub-orbital regimes (37).

4.8.4. Common technologies for all these vehicles include high energy fuels, multi-cycle high speed propulsion, high temperature tolerant materials and complex thermal management and flight control systems, in addition to similar aerodynamic challenges (37).

4.8.5. The first platform application of this technology would most likely be air breathing hypersonic missiles, designed to attack targets such as mobile missile launchers and other time critical targets. These would be capable of hypersonic speed (e.g. Mach 8 (2.5 km/sec.)), and have significant standoff range (e.g. 750 nmiles) (37).

4.8.6. Research into inherently unstable aircraft designs will continue. These require more capable and adaptive control systems, but are more responsive and maneuverable than stable configured airframes (40).

4.8.7. While current UAV concepts continue to develop, there may be a move towards miniaturisation of UAVs. This trend, enabled to a large extent by advances in computing and communications technology could lead to the development of a 'micro-UAV', with a 15 cm wingspan, weighing 100 grams and capable of 30 minutes operation. However, this would require advances in almost all areas, such as flight controls, propulsion, energy storage, sensors and communications. Achieving sufficient lift in a very small aircraft presents a problem, and weight restrictions preclude miniature actuators and movable control surfaces. An answer may be the adoption of 'circulation control' technology, which is based on the Coanda effect, whereby a thin sheet of high velocity air is blown

which is based on the Coanda effect, whereby a thin sheet of high velocity air is blown over a circular trailing edge to give increased lift and reduced drag. Actuators using adaptive materials to change the shape and pitch angles of lifting surfaces could also be used. MEMS technology, allowing navigation guidance and control on a single chip, would also be required for a feasible micro-UAV (41).

4.8.8. It is noteworthy that 95% of UAV usage is in the military sphere. Thus, while civilian applications for these platforms will inevitably increase, military demands will most likely remain a key driver in UAV development (42).

4.9 Nanotechnologies

4.9.1. The nanotechnologies field continues to develop. The aim is to enable engineering at atomic and molecular levels in order to create ultra microscopic structures. The nanostructures may be self-organising and adaptive, in response to external stimuli. Key drivers here are in the areas of medical diagnosis and treatment, but the potential for military application also exists.

4.9.2. Currently it is possible to manipulate molecules with microscopic probe elements, to form, for example, new proteins not found in nature, or help organic molecules assemble themselves into ordered patterns. However, there remains a large understanding and knowledge gap between this and the creation of intelligent robotic 'assemblers' no bigger than 100 nanometres across, complete with microscopic bearings and cogs.

4.9.3. Claims that such assemblers could then position reactive molecules individually to form a desired product are not credible by current levels of understanding, with questions relating to thermodynamics and information flow in a 'system' of assemblers being the chief stumbling blocks.

4.9.4. Should these assemblers be feasible, then it might be possible to rapidly create complex machines or spare parts from inexpensive raw materials. Likewise, such machines might be used in the opposite sense to dismantle a platform, such as a tank or aircraft, to give nothing more than a pile of waste. Medical applications could include seeking and destroying malignant tumors by injecting such nanomachines into the body (43).

4.9.5. Estimated timescales for the development of usable nanosystems, such as molecular assemblers, nanocomputers, and cell repair capabilities, vary widely from 2005 to 2050.

4.10 Space

4.10.1. Global military activities may become more dependent on space based assets and on commercial developments in space. The impetus for the latter comes from continuous constraints on military budgets, so that leasing of commercial, rather than owning, space assets is more cost effective (44). Competition means that high resolution images would be available on demand from commercial satellites. The advances in ground resolution provided by civilian satellites for the period 1972 to 2000, is shown in Figure 4 (20).

4.10.2. Future, commercially led space operations may be such that a massive space-based neural network will hover above the Earth by 2025. This would be promoted by proposals such as the Teledisic system, which plans to have 288 satellites in orbit by 2012, with the system possessing supercomputer processing capabilities (45).

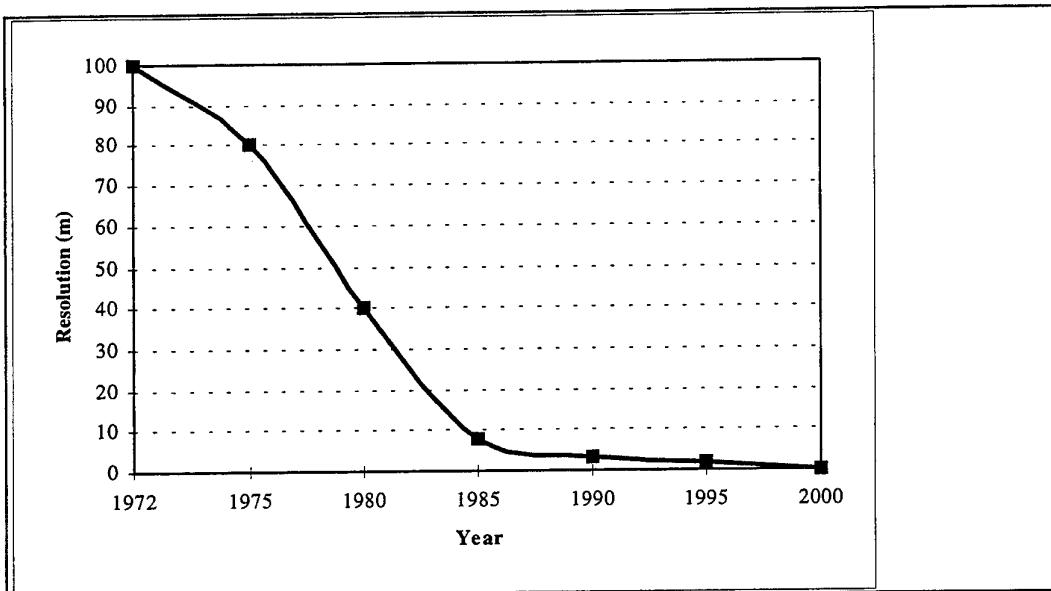


Figure 4: *Ground resolution provided by civilian satellites for the period 1972 to 2000 (20).*

4.10.3. Longer term military exploitation of space assets may include satellite based directed energy weapons, such as lasers, in addition to the current communications and surveillance capabilities.

4.10.4. The global positioning system (GPS) is the most common routine application of space based assets, and will allow increasing precision targeting in the future. Currently, a hand held receiver, using signals from 6 satellites can deduce position to an accuracy of 5 metres. Continuous improvement will deliver centimeter accuracy in the near future (20).

4.10.5. More efficient space lift may be afforded by developments in propulsion and platform systems. Developments in single stage to orbit (SSTO) technology would provide this efficiency, and may be achieved by advances including:

- linear aerospike engine configuration. This advance on traditional bell shape engine nozzle design allows for maximum engine effectiveness at all altitudes (46).
- use of low weight composite materials, such as graphite-fiber, instead of metal or alloy based materials. This is critical, since for each kilogram eliminated from a load taken into orbit, the amount of rocket propellant required is reduced by 8 kilograms (46).

4.11 Artificial Intelligence (AI)

4.11.1. The groundwork for artificial intelligence was laid over 40 years ago, yet in comparison to other technologies, developments since then have been modest in many areas of AI. One explanation offered is that while computers could apply 'reasoning' to narrowly focused and readily codified problems such as generating possible chemical structures or diagnosing illnesses, AI 'reasoning' could not readily cope with hard to codify tasks, such as face recognition. Also AI approaches tended to be too task specific, so that the system could not cope with a problem just slightly beyond its 'expertise' (47).

4.11.2. A number of AI approaches exist, the better known techniques being: Expert Systems, Case Based Reasoning (CBR) and Neural Networks, summarised as:

- Expert systems incorporate human expert knowledge into a computer program, to apply to 'similar' future problems, but cannot solve problems requiring knowledge outside of the

expert's field or expert knowledge which has not been 'captured' in developing the expert system (48).

- CBR suggests action by recognising similarities between current problems and previously solved occurrences. However, once present problems differ significantly from previous experience, the value of CBR is reduced.
- Neural networks use real world ambiguous data to determine relationships and make decisions. Decisions are reviewed to learn and improve the decision making process (15). Neural networks deal with 'noisy' data and are better at generalisation than the traditional symbolic approaches such as Expert Systems and CBR (48).

4.11.3. The optimal AI technique depends to a large extent on the problem to be solved. It is desirable that an AI system should provide prioritisation, control and monitoring functions, as well as 'graceful degradation' if parts fail. Combining all three allows a system to have both the knowledge necessary to make best decisions as well as the ability to learn from past events. Hybrid systems containing Expert Systems and Neural Networks are being developed to provide these desirable properties (48).

4.11.4. AI systems, like all computer-based decision systems, can be countered since corrupted input data would cause a degradation in AI decisions; like any software driven system, it is subject to information warfare (IW) attacks.

4.11.5. Advances in AI may mirror that of computer hardware and software developments. That is, faster more powerful computers would facilitate further development of AI techniques to provide an extended range of extremely useful AI techniques.

4.12 Human Factors

4.12.1. Rapid information processing demands can lead to overload and less than optimum human performance and decision making. Computers, artificial intelligence (AI), decision aids and variable displays attuned to workload can help with some of the processing aspects. Technologies for advances in information processing in 2020 are basically available now, except in the key areas of *cognitive science* and the *neurobiology of brain circuitry*.

4.12.2. Cognitive engineering is an essential part of the design of information displays and controls of future systems. Human - machine interface aspects must be understood, otherwise apparent 'improvements' may not yield overall capability advances, and may in fact lead to a deterioration in human performance. Thus, it is important to be aware of issues such as how much information is needed, how it may be presented and what level of automation is required, so that an activity is effectively carried out. Other technologies such as modelling and simulation, would support efforts in this field.

4.12.3. Advances in biotechnology and neuroscience offer the prospect of revolutionary advances for systems, including the 'human - machine' system, and operations. Biotechnology may also yield advances in weapon systems via the development of molecular information storage, as in DNA coding and 'molecular' computers. However, this would be a long term development.

4.12.4. Human machine interaction (HMI) will be in a state of 'interactive fusion' in 2020. The lead science in this area is 'brain mapping', whereby techniques such as EEG are used to monitor brain functions. Thus, EEG signals may become controllers of information presentation and content, as well as processing, leading to HMI optimisation (49).

4.12.5. Overall there may be a move from the human - machine 'boundary' as currently perceived, to human - machine *integration* techniques. In the shorter term this may allow voice or eye movement activated commands, while in the longer term they would allow 'think / action' capabilities, such as 'think / fly' or 'look / think / shoot'. The human and

machine become one functioning entity as a result of this integration. Technology advances may give rise to the notion of the 'cyborg warrior', and result in a 'blending' of the human and machine as one functioning unit. As the term *integrate* replaces *interface* to describe the new entity, a future cockpit or UAV control centre will have none of the displays or interfaces known to-day (50).

4.12.6. Ongoing research will yield a better understanding of human thought processes and biochemistry of memory. This may lead to an understanding and eventual control of the electromagnetic output of the brain, particularly the processes and perception capabilities beyond the range of five senses, including intuitive processes and 'gut-feelings' (50).

4.13 Electromagnetic Pulse (EMP)

4.13.1. The attraction of using EMP weapons is derived from:

- the development of sources capable of generating the required power and energy densities on the target at useful ranges, and
- the critical role played by miniaturised electronic components, such as integrated circuits, in many systems.

4.13.2. Typical electromagnetic pulse (EMP) sources are capable of peak powers in the range 100MW to 10GW, with average powers up to 10kW, and pulse repetition frequencies up to 1kHz.

4.13.3. EMPs by nature are less sophisticated than EW weapons, and allow more generic attack modes. An EMP weapon may cause burnout of target system, temporary upset or disruption of target systems, or jamming of microwave and RF receivers or radar systems, without needing detailed knowledge on target sensor systems such as may be necessary for the application of advanced EW systems.

4.13.4. EMP sources fall into two categories:

- Explosive: EMP is produced via flux compression generated by an explosive device, and
- Repetitive: the technology resembles that of conventional radar transmitters in principle, whereby pulsed high power microwaves (HPM) are generated via modulators capable of peak power outputs up to 10GW (51).

4.13.5. There is considerable ongoing research and development of EMP technology, and fielded applications are more likely in short- to mid-term rather than in the long term.

4.14 Laser

4.14.1. High power Diode Pumped Solid State Lasers (DPSSL) may be feasible when diode costs reduce and new and cheaper fabrication techniques are developed. Doubling of net efficiencies from the current 9 - 15 % (based on neodymium doped crystals) value will be obtained from routine engineering advances, while switching from neodymium to ytterbium doped laser crystals will also enhance efficiencies. Thermal management remains a problem for high power lasers based on this technology (52). Overall DPSSL advances tend to be limited by engineering, rather than fundamental scientific, considerations.

4.14.2. Semiconductor Lasers offer high efficiency, scalability to high power, low cost, low voltage requirements, compactness, wavelength agility and reliability. Most work in this area is based on AlGaAs and InGaAs materials, which lase in the region of 800 - 1000 nanometers, while most commercial devices are limited to 690 - 1500 nanometers. Lasers with wavelengths in the 2000 - 4000 nanometer range are based on Sb semiconductors (53).

4.14.3. Common systems, such as compact disk players, use IR lasers based on gallium arsenide (GaAs) and related semiconductors. Now there is considerable ongoing development work on blue lasers, based on wide-band gap materials such as zinc selenide (ZnSe) and gallium nitride (GaN) (54).

4.14.4. Blue lasers would allow greater storage density on optical disks, compared to current systems. Other potential uses are in higher resolution displays and in underwater communications systems (55).

4.14.5. Problems persist in attempting to achieve continuous blue laser operation at room temperatures, and relatively low energy requirements, using this technology. However, long life continuous operation of 10 000 hours may be achievable in the near future (55).

4.14.6. Phased arrays of semiconductor lasers utilising a number of beam steering approaches, and with total system efficiencies up to 15%, have been demonstrated (53). These have the potential of double the efficiency of diode pumped lasers

4.14.7. Other developments include multi-beam, fiber amplifier concepts. Here the output of many fibers are coherently combined, and allows operation at many wavelength bands (currently near-IR) depending on the dopant used in the fiber core. This allows scalability from tens of watts to megawatts using the same 'building blocks' (53).

4.14.8. Chemical Oxygen Iodine Lasers (COIL) have been developed over many years. Their main advantage is that it couples with and is transmitted very efficiently by optical fibers; thus offering the potential to locate the laser source remotely from its application (53). Use of other compounds in place of oxygen as energy transfer species may lead to more efficient systems. A continuous wave multi megawatt COIL system is the basis of the airborne laser (ABL) program now being developed by the US (56).

4.14.9. Allied to developments in laser sources are technologies to decrease beam divergence. Such decreases may be realised by decreasing output wavelengths, and increased beam quality and director diameter.

4.14.10. Active adaptive wavefront correction developments would obviate atmospheric and flight turbulence distortions and system imperfections. This may be accomplished via micro-electromechanical systems (MEMS) based low cost deformable mirrors for adaptive optics (57).

4.14.11. In general, advances in laser technology may be driven by commercial rather than military imperatives. However, high power laser developments may be driven by predominantly military requirements, since this technology is uniquely required for laser based weapons.

4.15 Sensors

4.15.1. The growth in computing power, plus advances in signal and data processing algorithms, means that enhancements to a sensor system may be derived more from the processing, than from the sensor, end of the system. Thus there is a trading of 'mass for MIPS' whereby improved processing power compensates for inadequacies in sensing hardware. An example is the adoption of a 'relaxed-optical-tolerance-imaging' approach to overcome problems associated with space based large aperture optical sensors. Here, the high structural integrity, rigidity and cost demands of these systems is relaxed by using a device consisting of very thin mylar surface stretched over a skeleton structure. The large aberrations associated with such a device may then be overcome by advances in post-detection processing afforded by improved computing power (58).

4.15.2. There will be an increased use of multiple physical phenomena in the sensing process. Thus, concepts for multi, hyper and ultra spectral optical imaging using

information from many spectral bands may be developed ³. Such sensors covering the thermal IR (3-12 microns) region offers day/night capability for target detection, recognition and identification. Multispectral sensing would allow future satellite based commercial systems to have spatial resolution down to 4 metres. Ultraspectral systems, operating at LWIR may be used for detection of gases such as vapours, CBW agents and pollutants (59). Also, combining optical, RF, seismic and acoustic data will lead to target detection and characterisation, with lower error rates, since information provided by each sensor type is 'additive' rather than 'repetitive' (58) (12).

4.15.3. Commercial satellite sensor thrusts are in two main areas:

- towards high resolution panchromatic data (e.g. 1-3 metre) for imagery, engineering and land use applications, and
- towards multispectral data for agriculture and other resource applications.

4.15.4. The latter could also be exploited for military applications, in the context of remote sensing, so that spectral imaging could generate terrain categorisation of the battlefield (59).

4.15.5. There may be increasing emphasis on data and information fusion at all levels of the sensing process. Thus, most capability enhancements may be via the integrated use of multiple sensors, giving a 'system of systems' (12).

4.15.6. Electro-Optic (EO) sensors may move from merely a sensing and detecting role, to include target designation, communications, control and potentially signal processing (27).

4.15.7. Focal plane array (FPA) technology allows high spatial resolution in devices from ultraviolet to long wave infrared range, although currently visible device technology is more mature than that of IR. However, FPAs based on PtSi, InSb and HgCdTe, in the 2 - 5 micron spectral region are becoming available in arrays up to 1024 by 1024 pixels. HgCdTe arrays (480 by 640 pixels) for the 8 - 12 micron region have been demonstrated, in addition to smaller arrays sensitive to two spectral bands simultaneously. These arrays would have application in FLIR, image seekers, IRST, situational awareness, threat warning and surveillance (60).

4.15.8. Future developments in FPA technologies may focus on large format, high density arrays. Array size may continue to grow, while pixel size may decrease. Multispectral FPAs could collect simultaneous images from two or more bands to give better target identification and clutter rejection for smart weapon systems. Cooling problems are being addressed via new technologies such as micro machined silicon bolometer arrays and ferroelectric FPAs (60). More advanced FPA technologies include quantum well IR photodetectors (QWIPS) and strained layer superlattices. Significant development work is required for these latter technologies, but they could lead to dramatic improvements in performance.

4.15.9. The role of laser radars may be expanded to include applications such as target recognition, 3-D imaging, wind sensing, gas cloud analysis, wire detection, terrain following and obstacle avoidance. A multimission system could offer target detection and identification, laser communications, missile warning and IR missile countermeasures (60). However, laser safety remains a key issue in their development so that the emphasis may be on the wavelengths above 1.4 microns or below about 0.35 microns.

4.15.10. A key commercial driver for laser radar developments may be in the field of safe operation of aircraft and motor vehicles, owing to the lasers ability to detect microbursts and vortices near airports, and their application in collision avoidance devices (61).

³ Multispectral consists of *tens* of bands, and bandwidth of 0.1 microns; hyperspectral consists of *hundreds* of bands, and bandwidth of 0.01 microns; ultraspectral consists of *thousands* of bands, and bandwidth of 0.001 microns (Reference 27, page 156).

4.15.11. Developments in broad band chemical and biological sensors, based in part on lasers, capable of identifying multiple agents will continue. The area of medical countermeasures may develop in concert with this (23).

4.15.12. Millimeter (mm) wave systems offer smaller beamwidths, higher gain and improved spatial resolution, compared to microwave systems. This is achieved utilising smaller and lighter antennas than for microwave systems. Thus, there may be increasing use made of sensors based on the millimeter wave (mm) spectral region. While offering lower resolution than the EO sensors, they have the advantage of being able to operate in adverse environmental conditions, such as cloud, fog, dust and darkness. At mm wavelengths, the brightness of radiation by bodies is fairly insensitive to temperature differences, thus in contrast to infrared systems, making mm wave detectors ineffective for detecting objects by temperature differences alone. However, highly mm wave reflecting objects, such as metals will be contrasted against an 'absorbing' background, such as rock, sand and vegetation, so that a radiometric image may be produced using these 'reflective' properties (62).

4.15.13. The ranges of mm wave radiometers is about the same as optical and IR based devices used passively. However, mm wave atmospheric attenuation does occur outside the 30 - 38 GHz and 75 - 110 GHz bands. The development of MMICs is a key enabling technology for mm wave systems, and it may be possible for both radiometric and mm radar to be incorporated into one system, offering both passive and active functions. Thus, mm wave systems offer high resolution LPI reconnaissance and surveillance capability, while mm wave homing devices could become more widespread in missile seeker systems.

4.15.14. Near term widespread commercial application of mm wave radar (77 GHz) in motor vehicle collision avoidance devices may mean a significant cost reduction in this technology (26).

4.15.15. Millimetre wave devices may provide imaging capability to complement EO and IR systems, via real-time imaging arrays and radiometric sensors. In addition, data fusion of mm wave systems with other imaging technologies would be enabled by advances in signal processing, such as superresolution techniques (62).

4.15.16. Passive millimetric radiometry may thus complement infrared and visible detection methods, since it can contrast highly reflective materials such as metals, water and plastics where reflected sky temperature is dominant (63).

4.15.17. Synthetic Aperture Radar (SAR) is currently operational in roles such as mapping, surveillance, target acquisition and treaty verification. Air and space borne SAR systems are presently limited by the need to transmit large amounts of data to ground stations for processing that is not 'real time'. However, on board real time processing to give photo quality pictures may be operational by 2020 (64).

4.15.18. Technological advances may allow SAR's role to expand into foliage penetration to locate concealed targets, mine detection and weapon guidance. An HF/VHF/UHF SAR may incorporate MTI capability and operate in all weather, day and night while allowing the platform to standoff beyond the range of enemy defences. This may be achieved via an ultra wideband (UWB) radar. However the main development issues are UWB antennas, high throughput signal processors and robust algorithms. This is highlighted by the fact that while current SARs require about 10 Gflops/sec, a VHF/UHF SAR will require 100s of Gflops/sec processing capability for acceptable performance (65) (66).

4.15.19. Miniaturisation techniques could reduce the mass and volume of SAR systems by a factor of 100 by the year 2020. Such systems could be mounted on UAVs, and capable of providing resolution in the centimetre range, and enabling classification of ground vehicles (64).

4.15.20. Overall, the trends in sensor development may be summarised as:

- continuous improvement via advances in resolution, bandwidth, ability to penetrate cover, MTI, integration, denser FPAs for EO sensors.
- increased use of multiple physical phenomena in the sensing process, e.g. multi, hyper and ultra spectral imaging, or combining information from EO and RF bands, reflected spectra and seismic responses to give improved detection and identification capability.
- greater connectivity between sensors of different types or at different locations, to give better sensor fusion (12)
- algorithm development to allow automated processing and distribution of raw sensor data to give the end user information and knowledge. Such intelligent functions would provide ATR, target classification and tracking and other outcomes (67)
- SAR systems capable of providing high quality images in real-time, and enabled essentially by advances in computing processing power.

4.16 Materials

4.16.1. A major driver for materials development is the fact that new airframes may have to last longer than previously, while existing airframes may have to last longer than original design lifetimes. This is brought about by the observation that capability enhancements are in the main, derived from new software, avionics, sensors, communications, EW and weapons systems rather than by developing completely new airframes. The very high cost of designing and developing entirely new aircraft, such as the stealth fighter, means that existing and currently planned airframes may have to last much longer than typical 'cold-war' aircraft. This makes increasing demands on materials development, inspection and repair technologies.

4.16.2. Other key drivers for materials development are affordability and environmental compatibility, while the emphasis for military aircraft could change from best performance to low cost at an acceptable performance (68).

4.16.3. Often there is a considerable time gap, perhaps 20 - 50 years, between the creation of a 'laboratory curiosity' material and its application in an engineering context (69). In addition, since the end of the cold war there appears to be an increasing emphasis on reducing production costs of advanced composite materials rather than developing new materials. Materials related technologies fall into the major areas of (a) new, including smart, materials and (b) understanding existing materials.

4.16.4. Developments in new materials technologies include:

- trend towards developing lower weight materials for given modulus and strength characteristics. For instance, aluminium is about 50% more dense than modern carbon fiber / epoxy matrix composites, while polymeric materials may have even lower densities. Addition of aluminium to titanium, nickel or niobium to form low density intermetallic compounds gives up to 50% weight saving and better mechanical properties (70). Carbon fibers exhibiting a 100% increase on current modulus may be developed, although cost is a significant factor, based on current fiber technology.
- covalently bonded materials incorporating elements such as boron, beryllium, carbon, silicon, aluminium and titanium, have the potential to provide stiffer stronger materials, with up to 15 times specific modulus of current materials, for engineering applications (70).
- incorporation of more composites for airframe construction. For example, US aircraft may move over the next ten years from 20% to 90% composite aircraft structure content (35).

Overall, while composites exhibit very high strength and good fatigue tolerance for fiber matrix structures, they have limited damage tolerance (70).

- high temperature tolerant materials. This characteristic is required in structural materials to tolerate the high temperatures generated by aerodynamic heating in, for example, hypersonic vehicles as well as in engines to allow greater thermodynamic efficiency. Materials such as silicon carbide composites may find application in jet engines, and allow higher turbine and combustor temperatures (71). However, the development of temperature tolerant materials may be difficult, since often materials offering good high temperature oxidation resistance, also exhibit high thermal expansion coefficients, such as hafnium diboride (71).
- structures designed for inspection and repair. Potential problems in remote and difficult to access elements may be assessed, via techniques such as laser generated ultrasound through flexible fiber optics threaded through the structure and MEMS. The immediate benefit of this is that such structures do not have to be disassembled for inspection (72). Thus, the usage and behaviour of a structure is monitored and recorded.
- smart materials and structures. Smart structures sense external stimuli and respond with active control, and have both sensing and actuator elements which may be embedded or attached to an 'adaptive' structure. Typical sensors include fiber optics, piezoelectric ceramics and polymers, while typical smart structure actuators include shape memory alloys (SMAs), piezoelectric and electrostrictive ceramics, MEMS, magnetostrictive materials, and electro- and magneto-rheological fluids and elastomers. Applications of smart materials may include rotorcraft blades, aircraft wings, air inlets, engine nozzles, large deployable precision space systems and robust microspacecraft. Expected benefits include enhanced handling qualities, vibration suppression, alleviation of noise and vibration and monitoring of vehicle health. A near term use for smart structures is expected to be monitoring of vehicle health, via onboard sensors connected to processors by a fibre optic network (68).
- self-healing structures. This is an extension of the smart structure technology, whereby monitoring of a structure allows active crack repair, via the incorporation of 'smart' repair materials, thus prolonging the lifetime of the structure (73) (74).
- integration of structural design and materials science, such that materials properties are matched to structural requirements. Thus engine performance may be improved by optimising structural materials properties relating to density, strength, stiffness and temperature tolerance (70).
- development of other materials. These include organic conductors, based on a number of polymers, and magnetic materials. Techniques to form materials with 'tailor made' electronic and optical properties are advancing. Thus, for example 'bandgap engineering' is achieved via controllable deposition systems for semi-conductor thin films, such as molecular beam epitaxy and chemical vapour deposition (75). Such multilayered semiconductor structures would have application in IR detector imaging arrays. These semiconductors would allow multispectral imaging using one focal plane array, rather than separate arrays for each wavelength band, thus providing greater target discrimination (75). Other materials could be developed for specific functions, such as high performance dyes for eye protection from lasers, and optical holographic materials based on photosensitive silica glasses (76).
- high temperature superconductors. Although superconductivity at relatively high temperatures such as room temperature may not be possible, developments of superconductors, for example based on copper oxide compounds, may continue to offer higher temperature operation. They may have application in microwave communications systems. RF circuits using superconducting thin films would give orders of magnitude performance increases, while size and weight are reduced (75). However, applications

may be longer term (greater than 20 years) rather than near term⁴. Non destructive evaluation (NDE) of structures may be facilitated using hand-held scanners based on superconducting materials.

- non-linear optical (NLO) materials. Devices based on NLOs have advantages over electronics based systems, such as immunity from electronic interference, low-loss transmission, large bandwidth and security, as well as small and light weight, and offer many orders of magnitude increase in computing power. NLOs can improve performance and character of laser sources, by capabilities such as wavelength conversion and amplification. NLO materials in current use include lithium niobate, while promising candidates include barium titanate and lithium tantalate (77).
- modelling techniques. These are being developed to design new materials in the areas of propellants and high energy materials and molecular magnetics.
- materials computer modelling. Developments whereby materials fabrication and application are modelled, rather than created in the laboratory, have up to now been limited by available computer hardware processing power. Increasingly software is becoming more limiting as modelling becomes more sophisticated with concomitant demands for algorithm development (78).

4.16.5. Developments in technologies related to existing materials include:

- development of deterministic models to predict corrosion and damage growth.
- development models to correlate microstructural feature changes with overall structure changes, i.e. to determine the 'effects of defects' (72).
- detection of cracks. Present low frequency eddy-current methods for inner layer crack detection may give way to robotic handling of inspection systems, allowing automatic scanning over large areas.
- corrosion detection. This may be facilitated via small wireless embedded sensors and indicator systems, such as thin film, bimetallic galvanic sensors, and may assist in developing a condition based maintenance (CBM) philosophy
- compact portable imaging devices based on both neutron and x-ray inspection techniques would enhance detection of structural corrosion and fatigue cracking. However, this would demand advances in computing, for both processing and storage capabilities, to cope with the large amounts of data generated (72).

4.16.6. Overall, increases in sensitivity and speed (factors 3 - 10) in detecting defects, as well as the more sophisticated NDE techniques, should lead to reductions in platform downtime.

4.16.7. In the longer term there may be a move from monofunctional materials (e.g. epoxy resins, optic fibers) to the formation of structures in which multiple functions are integrated by molecular design in one material, as in biological systems. Applications could include a 'function-integrated material' that is structural, functions as an antenna or sensor, as well as providing stealth capability. Materials offering promise for such functional integration are nanophased organics and nanophased composites (74) (79).

4.17 Energetic Materials

4.17.1. Rocket propellants have remained virtually unchanged over the past 40 years. However, this may change as major drivers such as performance enhancement, cost, availability, toxicity, environmental effects and safety exert influence.

⁴ Technology for making josephson junction circuits needs development for significant processing applications.

4.17.2. Endothermic fuels offering more effective use of energy produced on fuel combustion, may have application in both aircraft and rocket propulsion. These fuels use the 'waste' heat from combustion in the engine, to create a more energy dense and better combusting fuel. When heat is absorbed the endothermic fuel produces hydrogen and an alkene (olefin), with the added benefit of cooling the engine. The products are then burnt to provide energy. Heat sink fuels of this type may be introduced in the short term (by 2005) (80).

4.17.3. Other developments in this area would see one fluid used as both a fuel and lubricant. This offers weight savings due to the elimination of a number of engine components, but involves considerable technical risk.

4.17.4. Explosives may be 'tunable' in that the output can be matched to mission requirements. There may be increasing emphasis on high energy 'density' explosives for incorporation into micromunitions, and materials such as polymeric nitrogen have potential in this field (81).

4.18 Simulation Technology

4.18.1. Developments in a number of areas, particularly computing power, communications and artificial intelligence, may lead to advances in simulation technology, including:

- Image generation to provide high fidelity scene rendering. Current systems do not allow eye-limited resolution, owing mainly to a lack of sufficient computing power. Techniques such as retinal laser projection allows the possibility of eye-limited resolution and an unlimited field of regard (16).
- Displays to give increased brightness and resolution, in flat panel displays, projectors and helmet mounted displays. Advances in display systems may be driven mostly by the home entertainment market, and include high performance display technologies such as liquid crystal, electro-luminescence, thin film transistors and micro-mirrors (82).
- Dynamic environment models, rather than the current static models, would give total environment characterisation, including aspects such as visual, IR, terrain quality and atmosphere.
- Computer generated forces (CGF) consisting of intelligent entities with validated behaviours and interactions may populate synthetic environments.
- Integrated networks may link all levels and incorporate C4I, thus affording greater interoperability via advanced distributed simulation architectures.
- Simulator systems that are reconfigurable, flexible, deployable and interoperable, while emphasising COTS components and low cost, could become the norm (82).
- The tremendous advances in personal computing capabilities means that the 'lower-end' simulation market could grow rapidly, while overall costs would show a marked decline (83).

5. Application of Technology

5.1 Issues

5.1.1. Capability and advantage often reside in the application of a mature technology, or integration of technologies into a system, rather than in attempting to adopt 'breakthrough' technologies as they occur. For instance, the World Wide Web, which is experiencing rapid growth and revolutionising the way we communicate, uses well known and mature communications and computing technologies in order to function.

5.1.2. Often a technology will be adopted and applied only after complementary developments in another technology. For instance, computers in general were considered just a curiosity by most, and only with the development of software packages such as spreadsheet applications, were they seen as providing any real benefit to the broader community.

5.1.3. Cultural aspects may influence the application of a technology. For instance, there has been reluctance in certain quarters of the USAF community to accept UAV technology.

5.1.4. Cost is a major factor in the issue of adopting new capabilities, even though they may be technologically feasible. For instance, in the US it is assessed that a space based follow-on to AWACS may be delayed for a number of years, despite it being technologically feasible now, because of cost (84).

5.1.5. The 'gap' between a technology development and its eventual incorporation into a system offering capability advances is often difficult to bridge, with some advanced applications depending more on serendipity than foresight or inspired planning. One way to address this problem is via the use of advanced technology demonstrators (ATD). Such an approach, done with imagination, allows a relatively quick assessment of emerging technologies and their potential for capability enhancements. However, it is important to view ATDs as experimental or research in nature, so that unpredicted or less than expected, outcomes are not viewed as failures.

5.1.6. Human factors aspects must be considered when procuring a 'new' capability. The result may mean that capability 'support' items, such as simulators and training packages are obtained first, rather than last, so that necessary changes may be incorporated from the start to maximise human machine interaction.

5.1.7. Current world order does not push the development of technology in a military sense. However, the emergence of another superpower, allowed for in *Alternate Futures* planning, might:

- accelerate the rate of technological development and its incorporation into a system; i.e. narrow the timeframe between technological innovation and its application to provide enhanced capability, and be driven by military rather than commercial imperatives, and
- encourage the belief that a 'smart edge' is required, which would also contribute to this rate of acceleration. This belief would be enhanced if the capabilities of an emerging power were to depend more on the application of large quantities of relatively low technology based weapons, rather than on technological sophistication, information warfare or advanced concepts.

5.1.8. Rapid technological advances and costs may lead to the military fully adopting concepts of hiring commercial and civil, rather than owning military, capabilities. Currently, the ADF rents fibre communications networks for about 50% of its communications payload, and may do so for satellite communications in the future (44).

5.1.9. Better use of technology is also a key issue. The tendency to place trust only in the adoption of the latest high risk technology has to be avoided, since real advances may be accomplished by more effective application or better integration of existing or mature technologies.

6. Impact of Emerging Technologies on Future Air Capabilities

6.1 Overview

- 6.1.1. While technologies can lead to new strategies, for example, the employment of stealth and precision guidance technologies in the Gulf war, there is no attempt here to describe the impact of technology in the context of developing new strategies. Rather, technologies and systems are described in terms of their impact on specific air capabilities.
- 6.1.2. Emerging technologies or systems and their possible impact on future air capabilities are described under the broad air capabilities of Awareness, Reach, Power and Support. Systems, defined as functionally related groups of elements that perform a mission or task, are included in addition to the technologies, since often capability enhancements are afforded by incorporating known technologies into a system.
- 6.1.3. Australia's interest in exploiting these technologies and the potential for developing indigenous or niche capabilities is addressed.

(A). AWARENESS

6.2 Communications: Space Based

6.2.1. Key Features and Enabling Technology

- Direct Broadcasting Satellites (DBS) provides 'asymmetric' communication via large bandwidth multi-channel broadcast, and a narrow band return.
- DBS is a commercially driven development, which is independent of land lines.
- Mini Satellites allow low launch cost, launch flexibility and low unit cost.

6.2.2. Potential Impact and Implications for Australia

- DBS allow in-time inputs through a command and control system.
- Australia would buy commercially provided DBS capability rather than develop indigenous capability.
- Mini-satellites are small and numerous, so they have built in redundancy and are difficult to detect and track.
- Australia would not develop an indigenous mini-satellite launch capability in the shorter term.

6.3 Communications: Millimeter Wave and Laser based

6.3.1. Key Features and Enabling Technology

- Air to ground and air to air line of sight communications is accomplished by millimeter (mm) wave in the 38 GHz band. Satellite communications is accomplished in the 40 GHz band, with short range communications in 60 GHz band. Attenuation by atmospheric oxygen limits range in the latter band.
- High bandwidth of millimetre wave communications allows quicker data flow rates.
- Narrow beams and lower space requirements for mm wave systems make detection of both signal and platform difficult.

- MMICs are key enablers for mm wave communications.
- Laser operational frequencies in the range 10^5 - 10^6 GHz allows high frequency agility compared to radio frequency systems, and offers broadband, line of sight, communications capability.
- Longer term developments in semiconductor optical phased array laser technology would allow flexibility for one system to be used for communications, illumination, target tracking, PGM designator and a weapon (85).

6.3.2. *Potential Impact and Implications for Australia:*

- There is a lower risk of interception of mm wave communications owing to narrow beams and line of sight operation (25).
- Atmospheric attenuation restricts range in the 60 GHz band (mm wave), thus offering 'in-built' transmission security between relatively close platforms.
- Australia is leader in MMIC technology development, which could be a niche area offering both enhanced capability and a contribution to self-reliance.
- Diode lasers now offer short range secure communications capability, to become longer range in the medium term.
- Diode lasers could be applied in the roles of: weapons self defence, IRCM, anti-ground based targets, LPI wideband communications, IFF and target illuminator-designator.
- Flexible phased array laser technology is envisioned for a 30 years time frame (85). This laser system would be embedded in the aircraft skin, indicating that such a system would be an inherent design feature of a future aircraft. Resource considerations, and a clear requirement to amortise costs over large numbers of systems, means that Australia would co-operate with other parties rather than develop a unique indigenous capability in this area.

6.4 Sensors (General)

6.4.1. *Key Features and Enabling Technology:*

- Advances in computing power leads to more effective signal processing. As a result, emphasis may be on processing rather than on transmission and receiving technologies. Trading of 'MIPS for (radar) mass' means that sensors could become relatively smaller and lighter, but any reductions in performance would be more than compensated for by greater signal processing power (27).
- In addition to sensing and detecting, electro-Optic (EO) sensors may include target designation, communications, control and potentially signal processing.
- Sensors may be developed to provide complementary, rather than duplicated, data to give better accuracy and reliability. This adds redundancy in cases where one type of sensor may be ineffective (86).
- While multispectral imaging is currently well known, hyperspectral imaging may become more widespread as technology matures. Here the electromagnetic spectrum is divided into many narrow bands for collection. Fusion of the data from the various processing stages allows the construction of a target signature. A target may avoid detection in parts, but most likely not all, of the spectrum. Hyperspectral sensors would require airborne or space based platforms (86).
- Ground based sensor platforms may rely heavily on micromechanics and nanotechnology to shrink sensors to microscopic size. Except for micromechanical platforms, the

hardware for most sensor platforms exists now, but development of sensor technology is more critical (86).

- MEMS transducer based sensors offer greater ranges of operational conditions and low cost. The transducer, based on electronic tunneling, can be used to sense any phenomenon, and may have application in accelerometers, hydrophones, magnetometers, current sensors and broadband uncooled IR sensors (60).
- Focal plane array (FPA) technology allows high spatial resolution in devices from ultraviolet to long wave infrared range.
- Photonics are key enablers for broadband phased arrays, in addition to having more inherent self protection (25).
- FPAs based in the 2 - 5 micron spectral region are becoming available in arrays up to 1024 by 1024 pixels, while 480 by 640 pixels arrays for the 8 - 12 micron region have been demonstrated (60).
- FPAs sensitive to two spectral bands simultaneously may also be developed.
- Future FPA technologies may focus on large format, high density arrays. Thus, while array size continues to grow, pixel size decreases.

6.4.2. Potential impact and Implications for Australia:

- Smaller more capable sensors may be deployed on platforms such as UAVs and mini satellites.
- Small size and relatively low cost makes such systems difficult to counter, owing to 'in-built' stealthy characteristics, and redundancy afforded by large numbers.
- It would be difficult to counter integrated sensor systems based on broad- and multi-spectral phenomena.
- EO systems offer high resolution for unambiguous target identification, and application in seeker systems.
- Development of complementary sensors, and hyperspectral systems, is more cost effective than attempting to maximise performance of sensors based on one spectral region.
- FPAs would have application in FLIR, image seekers, IRST, situational awareness, threat warning and surveillance (60).
- Multispectral FPAs could collect simultaneous images from two or more bands to give better target identification and clutter rejection for smart weapon systems (60).
- Australia could become involved in sensor technologies, particularly in the areas of software development, sensor fusion and integration, since these areas offer the greatest capability advances.

6.5 Millimeter Wave Radar and Radiometry

6.5.1. Key Features and Enabling Technologies:

- Allows passive sensing for missile warning and surveillance within line of sight in 35 to 94 GHz range. There is some atmospheric attenuation within this range.
- Allows passive imaging and foliage penetration; and low weight and volume requirements facilitates incorporation on UAV platforms.
- MMICs are a key enabling technology for mm wave sensors (26).

6.5.2. Potential impact and Implications for Australia:

- Can integrate with other sensors for missile warning, whereby IR sensor detection of the missile plume is ‘fused’ with mm wave detection of the missile body.
- System offers smaller beamwidths, higher gain and improved spatial resolution compared to microwave systems.
- Systems can operate in adverse conditions (fog, cloud, dust, darkness).
- There is considerable indigenous expertise in this field, both for the radar and MMICs, so this could be developed as a niche area for Australia.

6.6 Laser Radar

6.6.1. *Key Features and Enabling Technology:*

- Laser based light detection and ranging (LIDAR) sensors may detect and analyse chemical and biological agents in the atmosphere. Their compact size makes them adaptable for satellite and UAV platforms.
- Laser radars may be applied in the areas of target recognition, 3-D imaging, wire detection, terrain following and obstacle avoidance.
- Laser radar allows high resolution, e.g. 30cm range resolution, they are not covert and could combine with other sensors to provide multispectral data.

6.6.2. *Potential Impact and Implications for Australia:*

- Early Australian application most likely in obstacle avoidance.
- Broader application may be in the areas of chemical and biological agent detection and analysis.
- A multimission system could offer target detection and identification, laser communications, missile warning and IR missile countermeasures, while at the same time have low space and weight requirements (60).
- Both the human eye and electro optic sensors are sensitive to visible laser energy, and can be permanently damaged, even by low intensity lasers. Thus, the issue of safety of operation and protection is imperative as laser systems become more widespread.

6.7 Synthetic Aperture Radar (SAR)

6.7.1. *Key Features and Enabling Technology:*

- SAR techniques produce larger quantities of data and require higher capacity processing capabilities compared to non-SAR radars.
- Broad band communications systems are required to transmit large amounts of data by line-of-sight to ground stations for processing.
- Real-time on-board processing of photo-quality pictures may be operational by 2020 (64).
- Miniaturisation techniques are expected to reduce mass and volume of SAR systems by a factor of 100 by 2020 (64).
- There would be tradeoffs between coverage and resolution. Satellite scenes of areas 100 x 100 km may be processed in real-time to one metre resolution. Smaller scenes from lower flying platforms would provide resolution in the centimetre range.
- SAR techniques may also be applied at UHF frequencies.

6.7.2. *Potential Impact and Implications for Australia:*

- Real-time photo quality images would allow rapid identification of ground targets.
- Resolution in the centimetre range would enable classification of ground vehicles.
- UHF SAR techniques would permit limited penetration in dry soil and shallow water, with somewhat reduced resolution (64).

6.8 Data Fusion

6.8.1. *Key Features and Enabling Technology:*

- Data fusion is the processing and combining of data and information from many sources to a level of accuracy and completeness required for a task (64).
- Such a process may be accomplished in a matter of seconds in the future, enabled by advances in areas such as high speed computing, communications and artificial intelligence (AI).
- Real-time data fusion from non-collocated sensors would require robust, high data rate inter-sensor communications (64).
- Data fusion uses a variety of mathematical methods, with the simpler methods applying when data is 'similar', e.g. pictures taken of the same scene at the same time, but in different frequency bands, by the same sensor system (64).
- More complex data fusion methods may use AI type associative processes, for example to fuse data of different types, such as data from radars, electronic intelligence and eyewitness reports.
- Data fusion may be used to extract useful information at the sensor. Thus, the only information transmitted might concern the identification and location of a specific object, rather than a complete image from the sensor.

6.8.2. *Potential Impact and Implications for Australia:*

- Data is rapidly fused, analysed and communicated to the appropriate commander, so that the decision cycle is both shorter and better informed.
- Packets of information may be tailored to meet the needs of the individual. Thus a theatre commander and a tactical commander would receive different 'levels' of information on the same activity.
- Extraction and transmission of required information only, places much less demands on communications system capabilities.
- Since data fusion may lead to better situation awareness, there would be less risk of false alarms and some protection against jamming and spoofing (64).
- In future the 'picture' presented to a pilot in the cockpit may be derived by data fusion from many and dispersed sources, and possibly excluding the pilot's own platform.

6.9 Artificial Intelligence (AI)

6.9.1. *Key Features and Enabling Technology:*

- AI aims to emulate the problem solving capability of human experts. AI permits a computer to create timely information from vast amounts of data derived from many sources and in different forms (86). AI techniques may organise the large quantities of data into information packages of a manageable size, and ensure that the decision maker obtains pertinent information, in a timely manner.

- AI techniques may be used to fuse target acquisition data, provided by broad spectrum sensors (e.g. radar, EO, acoustic, chemical), using broad band communications media, and provide timely relevant information to the decision maker.
- Large computational processing and storage capability, as well as innovative new software developments would facilitate the development of AI techniques for solving previously extremely difficult or intractable technical problems (48).

6.9.2. Potential Impact and Implications for Australia:

- Allows more effective and efficient use of information, since a commander would be provided with all relevant information needed for effective and timely decision making. The AI algorithm used might also suggest a preferred decision option (with reasons) for the commander.
- Decision making could be speeded up by using appropriate AI techniques, thus providing timely and appropriate actions, while at the same time making it difficult for an adversary to 'get inside' Australia's OODA loop.

6.10 Uninhabited Air Vehicle (UAV)

6.10.1. Key Features and Enabling Technology:

- UAVs may be used as communications relay platform to provide the bandwidth to track battlefield mobile targets, and would assist in data fusion from many sources.
- Agile communications systems, using frequency hopping, and cross frequency message distribution techniques, on airborne networks help deny information to other parties.
- Miniaturisation of sensor packages allows greater use of smaller platforms, such as UAVs.
- UAVs could be employed as a platform for standoff detection of biological and chemical warfare agents, using for example, compact and lightweight LIDAR sensors (87).

6.10.2. Potential Impact and Implications for Australia:

- There may be wide spread use of UAVs operating both as a communications and sensors platform.
- Relatively low cost of UAV compared to space based or manned platforms is somewhat offset by the substantial infrastructure requirements of UAV systems.
- UAVs offer a safer detection and characterisation of BW agents, owing to remote control, as well as standoff capability.
- Tactical surveillance and reconnaissance are the most likely short to medium term application of UAVs.
- Issues related to UAV capabilities, basing, infrastructure, training, amount of indigenous development and support, control and integration may impact on Air Force future planning.

(B). REACH

6.11 Aircraft Propulsion Systems

6.11.1. Key Features and Enabling Technology:

- The IHPTET program aims to increase engine power to weight ratio by 100%, while decreasing production and maintenance costs by 35%. Increases in engine performance

already realised from this initiative are feeding into programs such as the F/A-18 E/F, F-22 and JSF.

- Technology developments contributing to these advances include improved aerodynamic design, better internal cooling, new combustor designs, reduced engine stages and engine components and innovative structural features such as integrally bladed rotors (88).
- Advances in materials technologies such as superalloys for blades and discs, metal-matrix composites for rotating structures and ceramic-matrix composites for combustors will contribute to increased engine performance (88).
- Vectored thrust in both vertical and lateral dimensions leading to greater maneuverability may become more widespread.
- Small turbojet systems may be developed for use in UAVs, while innovative propulsion systems may be developed for micro-UAVs, for instance flapping wing propulsion using electro-strictive polymer artificial muscle actuators (89).
- Smaller, cheaper propulsion systems offering order-of-magnitude improvements in performance enable small, long-range missiles (88).
- Ramjets for propulsion of high performance missiles may be developed.

6.11.2. *Potential Impact and Implications for Australia:*

- Ramjet/scramjet powered missiles would have higher velocity, range and maneuverability compared to current systems, thus affording greater stand-off capability.
- Australia needs to be able to model and assess the performance of supersonic ramjet propelled systems (88).
- Small, fast, long range missiles would be difficult to counter.
- Australia would need to bear in mind such high performance missile systems when contemplating capabilities of new aircraft.

6.12 Airframe Materials

6.12.1. *Key Features and Enabling Technology:*

- Main drivers for improved airframe materials are weight reduction, improved performance, reduced acquisition cost and reduced through life support cost (74).
- In the short to medium term advances in metal alloys may lead to performance improvements. Newer lithium aluminium alloys would provide greater stiffness to density ratio, with good corrosion and fatigue resistance (74).
- Major limitation for metals continues to be weight for aluminium and titanium alloys (specific gravity 2.7 and 4.5 respectively, compared with 1.6 for graphite epoxy composites) and susceptibility to damage by cycle loading (fatigue) and corrosion. However, relatively low cost and resistance to mechanical damage are two key advantages provided by metal airframe materials (74).
- There may be greater use of advanced composite materials, such as graphite/epoxy resins, in airframe structures, in the short to medium time frame. However, while composites offer toughness and strength there remains the problem of poor resistance to mechanical damage. A main focus of composites in the short term is to reduce fabrication costs.
- Hybrid metal/composite laminates incorporating advantages of both metal and composite may be fabricated, with cost between aluminium alloys and polymer matrix composites.

- Composites may incorporate ‘buried’ sensors and actuators, thus giving ‘smart’ materials. These structures would react or adapt to the external environment, e.g. monitoring or preserving structural health, or by changing shape as an aerodynamic surface. Embedded activators could also reduce stress and vibration, and encapsulated resins could provide a self-healing capability (74)
- Smart materials may be incorporated in aircraft structures and may combine with fast computers running active control systems to manipulate these materials.

6.12.2. *Potential Impact and Implications for Australia:*

- Composite structures would reduce airframe weight and lead to lower maintenance costs, particularly costs resulting from environmental (corrosion) and fatigue sources (90).
- Over the medium term, future military aircraft may continue to be made of a mix of conventional alloys, advanced alloys and advanced composites. The selection would be largely based on the cost of weight savings compared to the value of weight saved, based on improved performance, such as unrefuelled range. Weight savings for combat aircraft and UAVs would be particularly valuable. Future cost reductions in composite manufacture would swing the balance more in their favour (74).
- In the short term, use of smart materials in aircraft structures, such as helicopter rotor blades, would lead to reductions in the magnitudes of fatigue loads, cabin vibration and both internal and external noise, as well as contributing to enhanced handling. This would result in better crew performance as well as lower platform noise signature (90) (68).

6.13 Platforms - Aircraft and UAV

6.13.1. *Key Features and Enabling Technology:*

- Feasible hypersonic systems would afford transit times a fraction of that taken by current advanced platforms.
- Fewer nations might develop weapons systems, particularly platforms, so that capability differences would depend on the status of the weapons system released by the supplier and indigenous ability to use and support equipment (91).
- Military platforms designed with increasing emphasis on low observability (stealth) rather than purely aerodynamic requirements (92). Low observability may be achieved both through design and usage of materials and coatings.
- In the longer term adaptive signature control may be realised.
- More precise structural durability assessments may be afforded via advanced analysis techniques for loads, crack propagation, fracture and effects of corrosion.
- Advanced NDE techniques would allow assessment of damage via safety by inspection, and lead to a ‘replacement for cause’ management strategy.

6.13.2. *Potential Impact and Implications for Australia:*

- Hypersonic delivery systems would afford very little warning time.
- Australia may contribute to major platform developments, particularly from the point of view of developing unique requirements.
- Australia would have to develop indigenous capabilities in low observable (stealth) technologies.
- More precise structural assessment and NDE techniques would lead to greater confidence regarding airworthiness issues, a ‘replacement for cause’ management strategy and higher platform availability rates.

6.14 Reusable Space Launchers

6.14.1. *Key Features and Enabling Technology:*

- Reduction in launch cost per kg of payload by factors from 3 to 10.
- Offers the capability to 'launch on demand'.

6.14.2. *Potential Impact and Implications for Australia*

- Military most likely to be customer of a space launch agency, rather than develop its own launch capacity (64).
- Australia unlikely in short term to require uniquely military space based systems.

(C). POWER

6.15 Weapons

6.15.1. *Key Features and Enabling Technology:*

- Weapons might be more accurate, and with explosive effectiveness per unit mass up to ten times current values. Differential GPS/INS system would be integral to provide precision guidance (93).
- There may be increasing emphasis in the shorter term (5 -10 years) on high performance, including hypersonic (Mach 6-8), air breathing standoff weapons giving longer ranges and high terminal speeds (94) (36).
- Hybrid propulsion systems (solid fuelled, air breathing ram rockets) would give longer ranges at higher speeds in short and medium range air to air missiles, in the shorter term (94).
- Smart missile propulsion systems would give increased velocity and maneuverability in the terminal stages via energy management and thrust control (94).
- There may be increasing emphasis on micromunitions, with high energy density.
- There may be increasing emphasis on munitions that are both scaleable and tunable (40).
- There may be significant increase, enabled mostly by advances in signal processing, in the capability of RF seekers to reject countermeasures and home onto the 'real' target (95).
- Active RF seekers for the anti air environment may be 'fire and forget', so that a launch platform need not track the target throughout the engagement (95).
- Passive RF seekers are likely to be combined with other sensors in dual mode applications (95).
- RF seekers may become more stealthy possibly via (a) conformal electronically scanned antennas to reduce radar cross section, and (b) power management to reduce the active radar signature of the missile (95).
- Millimeter (mm) wave seekers would increase in popularity as costs decrease. Future weapon systems may make use of all transmission 'windows' up to 220 GHz.
- EO seekers may have a full imaging capability.
- Imaging laser sensors may be used in seekers. They would provide high resolution imaging with range data at relatively low cost, and have better poor weather performance compared to passive imagers (95).
- Weapon systems may vary in sophistication and cost, and be broadly described as:

- (a) Low cost, such as a GPS guided bombs, e.g. JDAM
- (b) Medium cost, involving dual band or dual mode seekers. Such seekers have complementary capabilities, for example, the long range of a passive radar system and the high angular resolution of an IR system could combine to provide a more accurate standoff weapon, which is also more resistant to countermeasures.
- (c) High cost, involving multiple sensors offer enhanced performance and a degree of redundancy. The multi-sensors approach is enabled by cost reductions in sensing and processing technologies, and may involve concepts where sensors are distributed across many platforms and weapon guidance is augmented via datalink information from these other sources (95).
- Increasingly, the characteristics of weapon systems are being defined largely by the software they incorporate. Thus, an existing weapon system may remain effective for 20 years via regular software changes (95).

6.15.2. Potential Impact and Implications for Australia

- Smaller payload means that a missile may have increased range, and lower signature.
- High capability micromunitions may be carried by relatively small platforms such as UAVs. In essence the UAV becomes a ‘cruise missile’ that returns home after delivering a warhead to a target. However, this would require secure data links and a degree of autonomous control via AI, so that a mission may be completed even when a data link is lost.
- It would be difficult to defend high value large platforms against hypersonic guided missiles, which may become available within short to medium timeframe (less than 10 years) (92).
- Hypersonic air breathing missiles offer many advantages, including:
 - (a) very short flight times to target.
 - (b) air breathing reduces weight and increases range.
 - (c) significant standoff ranges, e.g. 750 nmiles (36).
 - (d) launch platform survivability enhanced as a result of greater stand-off range.
 - (e) self-survivability enhanced because of greater speed.
 - (f) may be used with OTH targeting.
 - (g) high kinetic energy provides greater destruction and target penetration.
- Adoption of hypersonic missiles would allow existing aircraft to be used as missile launch platforms to their life of type.
- It would be difficult to defeat missiles capable of high speed, long range and maneuverability and possessing smart seekers and guidance systems by ‘soft-kill’ methods.
- It would take the development of extremely high performance anti-missile systems to threaten a hypersonic missile system (64).
- Such missiles would change the rules of engagement for beyond visual range combat.
- ‘Fire and forget’ autonomous weapon capability would lead to greater delivery platform survivability, and a reduced requirement for high performance strike aircraft, since the weapon takes over many of the platform roles, such as target identification and long range approach to the target (95).

- Dual mode seekers would be expected to be more robust than single mode systems in the presence of countermeasures.
- Millimeter wave systems have the advantage over EO systems in that they can operate in more adverse conditions, such as cloud, fog and darkness.
- Imaging seekers offer greater sensitivity and angular resolution than earlier EO seekers. These seekers provide such large amounts of information on the target that it may discriminate countermeasures, such as flares. Also, greater target discrimination allows a missile to be fired from long standoff ranges (95).
- Low, medium and high cost weapons might co-exist in the timeframe under consideration; while choices based on target value, affordability, countermeasures, standoff considerations and other factors would determine the type of weapon chosen.

6.16 Electromagnetic Pulse (EMP)

6.16.1. *Key Features and Enabling Technology*

- EMP sources such as magnetically insulated line oscillator (MILLO) may reduce size and weight requirements.
- Repetitive, rather than explosive based, systems provide relatively low cost ‘firings’, together with greater flexibility.
- Ultra wideband (UWB) sources capable of delivering 25 GW peak power have been demonstrated.
- Deployable weapons system are feasible, and are determined by technical factors involving materials and antenna.
- EMP weapons are considered non-lethal, and may fill the ‘gap’ between taking no action and applying lethal force.
- UWB antennas could be available in planar arrays with electronic steering ability and very high power projection (96).
- There is the potential to design a system so it performs both as a radar and an EMP weapon.

6.16.2. *Potential Impact and Implications for Australia*

- EMP weapons do not require target acquisition, pointing and tracking capabilities, so there is significant capability even in the absence of target knowledge.
- EMP weapons have all weather capability, though some degradation of performance may occur above 10GHz frequency.
- An operational EMP capability may be available in 10 - 20 years. Both narrowband (for when target details are known) and UWB (for volume attack, or when target details less certain) systems could be developed.
- Shielding against EMP attack is difficult, owing to the potential for coupling effects in the target electronic systems.
- Hardening of systems, particularly aircraft flight control and mission critical systems, against EMP weapons may become a key design feature of any new capability.
- Australia has significant indigenous knowledge in this technology, so that EMP development could become a ‘niche’ area.
- An indigenous capability based on repetitive systems is more likely.

- The requirement to minimise casualties and to invoke only proportionate force may increase and drive ADF to evaluate and acquire non-lethal weapons (94).

6.17 High Energy Laser - Space and Air Based

6.17.1. *Key Features and Enabling Technology*

- Diode pumped megawatt class lasers would require new and cheaper fabrication and assembly techniques to become a reality for application in laser weapons.
- Greater efficiency plus developing InGaAs diode arrays and ytterium doped laser crystals, to give high power lasers in the 900 - 950 nanometer range, may provide the basis for a laser weapon. Problems with heat management would have to be overcome to make the system more compact, since current systems require twenty times more cooling mass (water-ice slurry) than laser material mass (52).
- Fielded weapon based on diode pumped lasers is feasible, and is limited more by engineering rather than scientific considerations.
- Semiconductor lasers could conceivably be incorporated as a phased array in the skin of an aircraft to provide a laser weapon capability. Electronic focusing allows high precision control of light from each diode (53).
- The chemical oxygen iodine pumped laser has been used in the development of the airborne laser weapon (ABL). Currently a COIL based ABL system is being developed in the US, and may be fielded in the short to medium term.
- Space based laser weapon systems may be developed in the longer term. This could incorporate an on-board system. Alternatively, a ground based laser source could be employed, with the space based platform employed to reflect the laser beam with precision onto a target.

6.17.2. *Potential Impact and Implications for Australia*

- Since lasers deliver energy, but not momentum to a target, lethality is achieved by thermal damage to susceptible thermally 'soft' target components, such as missiles, satellites, aircraft, people and sensors.
- Target hardening against laser threats may become a routine design feature of future systems. For missile targets, this may include the use of 'mirror' materials, intumescent coatings⁵ or by spinning the target so that the laser energy is distributed over a broader area of the missile body, thus requiring a greater time on target to achieve a 'kill' (97).
- Eyes and imaging sensors are particularly susceptible to damage owing to their focusing action of the laser beam.
- As a result of target hardening, lasers would have to attack with smaller spots at higher irradiance to accomplish a kill. This would require shorter wavelengths, higher beam quality, larger optics, adaptive systems and higher power.
- The emphasis of lasers weapons application may shift from merely jamming (e.g. against IR missile seekers) to actual thermal destruction of the target system, using a high power laser beam.
- An airborne laser (ABL) system is being developed, and is set to undergo its first 'firing' test early in the next decade for the purpose of theatre missile defence (TMD) (98).

⁵ Intumescent coatings absorb energy by 'charring', while allowing the substrate material to remain intact.

Specifically, it is intended to intercept, and destroy missiles in boost phase, at ranges greater than 400 km in a matter of seconds (97).

- The ABL system is based on a Boeing 747 airframe. However, with increasing compactness, efficiency and precision future laser systems may also be satellite or UAV based, and be applied in capacities additional to TMD, such as suppression of enemy air defences (SEAD), cruise missile defence, airborne asset protection and imaging surveillance (98).
- It is unlikely that Australia would develop such an indigenous ABL weapon capability. While estimated 'shot' costs may be relatively low at US\$ 1000 per shot (98), the high cost of procurement and development of a system may be prohibitive. However, future capability requirements and advances in laser technologies may change this perception.
- While Australia may need to consider laser weapons as possible solutions to ADF requirements, it is more likely that Australia's application of lasers would be in the sensors and communications fields rather than as weapons, at least in the short to medium timeframes.
- Australia should contribute research effort to the 'laser community', since countries developing laser technologies are unlikely to offer mature systems for sale in the short term (94).
- Lasers have the potential to uniquely impact on future military activities, due in part to essentially a 'zero-time-of-flight' of the weapon. Rather than be considered merely as another 'add-on' capability, their influence would be such that tactical and doctrinal issues need to be addressed in a fundamental way.

6.18 Uninhabited Combat Air Vehicles (UCAV)

6.18.1. *Key Features and Enabling Technology:*

- Up to 40% weight and volume reduction may be achieved in a UCAV, compared to manned aircraft carrying the same weapons or sensor payload. They do not have to be flown in peacetime to maintain currency, as operators and 'pilots' may train using all real combat features except for simulated aircraft. As a result, while initial UAV purchase costs may be similar to that of a manned aircraft, it may be stored for considerable periods, leading to 80% reductions in operating and support costs compared to the manned aircraft (99).
- Modular design philosophy may be adopted. Different modules to carry radar, EO or other sensor may be incorporated. Other variations, such as afterburners or vector thrust could be added to suit requirements. Thus while the former provides increased speed, the latter provides increased maneuverability.
- Maneuverability of a UAV would be greater than for manned aircraft, with 20g turns being routine. A low observable UCAV could perform the air to air combat role, by being capable of 12 - 30g turns and employing small, high performance missiles.
- Data links between the UCAV and operators may be susceptible to interception and jamming. A UAV system has to recognise this, and may incorporate some measure of autonomous operation into the platform, via pre-programmed flight directions, as well as ECCM techniques such as spread-spectrum transmissions.
- Extensive additional infrastructure, such as control and communications facilities and ground stations, is required to support UAV operations. The UAV may be controlled from an airborne manned platform, such as AEW&C, with access to long range sensors and high intelligence data capabilities.

- Development of small smart bombs enhances UCAV capability. They are based on the JDAM and Wind Corrected Munitions Dispenser, and are expected to weigh 100 - 250 lbs (99), so that smaller UAVs can carry loads with greater lethality.
- Current US design philosophy is to have very few high cost systems on the UAV, and in the absence of new drivers arising in the meantime, it is expected that an operational UCAV system could be fielded by 2015. Technical feasibility, cost and cultural acceptance are expected to be the main influences in the development of UCAVs.
- Operationally, UCAVs would most likely be employed in the air to ground role before the air to air role.
- Broad band communications, advanced computing, materials, micromechanical devices and human-machine interface are key enabling technologies for the UCAV concept to work.

6.18.2. *Potential Impact and Implications for Australia:*

- Speed, altitude, stealth and maneuverability combine to give increased capability in combat and ground attack role, in addition to enhanced survivability.
- Concepts for the employment of UCAVs will have to be developed, but options may include:
 - a) The UCAV incorporates expensive sensors, while the weapon incorporates a low cost terminal guidance system. In this case the UAV would go close to target, but the expensive sensors are not 'consumed' when (precision) strike is made.
 - b) High quality sensor information is provided by a stand-off control platform such as AEW&C. In this case the UCAV need only have low-cost sensors, and so be less costly to sacrifice.
 - c) The missile system possesses advanced seekers and guidance systems, coupled with high stand-off capability. In this case the UCAV need not have extensive sensors or smart systems. However, for such a combat system, the missile costs would be relatively high.
- It is unlikely that Australia would lead in developing UCAVs. Should the manned JSF development prove prohibitively expensive, the US might bring forward its UCAV program to replace current F-16s and F/A-18s (99). As a result Australia would have to consider a UCAV option to replace F/A-18 and F-111, in the period 2015 - 2020, rather than as an option to replace the following generation of manned aircraft.
- Costs associated with extensive UAV infrastructure requirements are significant, making this combat option less attractive, and more likely in the long term than in short to medium terms.
- For Australia, it is likely that UAVs may be confined to the tactical surveillance and reconnaissance roles in the shorter term. Their roles in wide area surveillance may be longer term, while their role as combat platforms is less likely in the foreseeable future.

6.19 Countermeasures

6.19.1. *Key Features and Enabling Technology:*

- Countermeasures are drawn from a number of technologies.
- Lasers may be developed as an effective countermeasure to missile EO seeker systems.
- Developments in computer technologies would enable advanced signal processing, while at the same time be able to contribute to countermeasures by spoofing and other jamming techniques.

- Computer and communications systems are vulnerable to attack by ‘viruses’ or the deliberate introduction of corrupted data and information.
- Information systems may have inherent reliability and fault tolerance as a design feature.
- Information systems may have inbuilt redundancy and self organising capabilities
- Advances in stealth technologies continue.
- A driver for developments in hypersonic systems is the realisation that stealth technologies may be overtaken by counter-stealth technologies.
- HPM systems are difficult to counter by electronic countermeasure techniques.

6.19.2. *Potential Impact and Implications for Australia:*

- Laser countermeasures may move from ‘soft-kill’ blinding capability to actual destruction of the missile.
- A challenge would be to recognise that a computer or information system has been compromised. A biological ‘model’ could be used to overcome this challenge. Here the system would recognise and neutralise an ‘intruder’ much as a biological system recognises a pathogen and excludes it by utilising antibodies or specific organs such as tonsils.
- The survivability of functions in a large distributed information system would be enhanced in a system with inbuilt redundancy and self organising capabilities. The latter capability allows for ‘graceful degradation’ when a system is subjected to an ‘information attack’ or has sustained damage or faults.
- ‘Stealthy’ systems would be increasingly vulnerable to multi-modal and multi-spectral sensor systems.
- Hypersonic platforms (aircraft and missiles) are inherently difficult to counter owing to speed and the greater stand-off capability of hypersonic missiles.
- Shielding and hardening of electronic devices would be essential to counter attack by EMP devices.

6.20 Information Warfare

6.20.1 *Key features and Enabling Technology:*

- Information warfare (IW)⁶ is a broad concept, and includes both information attack (IA)⁷ and command and control warfare (C2W)⁸ (100).
- Key enabling technologies are computing, communications and intelligent agents. These allow rapid gathering, processing and dissemination of information.
- IW relates to all aspects of information, and not just ‘information-in-war’. It is about ideas, beliefs, what is known, how it is known and would be ‘waged’ largely through an

⁶ Information Warfare (IW) is defined as “actions taken to achieve relatively greater understanding of the strengths, weaknesses, and centres of gravity of an adversary’s military, political, social and economic infrastructure in order to deny, exploit, influence, corrupt or destroy those adversary information based activities through command and control warfare and information attack” (100).

⁷ Information Attack (IA) is defined as “activities taken to manipulate or destroy an adversary’s information without visibly changing the physical entity within which it resides” (100).

⁸ Command and Control Warfare (C2W) is defined as “a war fighting application of IW in military operations that employs various techniques and technologies to attack or protect a specific target set – command and control” (100).

adversary's information systems and infrastructures. As a result, information is both the target and the weapon.

- IW is more than an adjunct to traditional mass-on-mass warfare. It also includes political, economic, physical and military infrastructure aspects. Thus, the former, and traditional, meaning of IW is more 'information-in-war', while the latter may be more dominant in the future in the context of information attack.
- Developing integrating techniques, including use of intelligent agents, means that commanders at all levels may get in-time, coherent and required information to make good decisions.

6.20.2 *Potential Impact and Implications for Australia*

- Information systems are vulnerable to IW, with emphasis on system function rather than system components. This impacts adversely on a commanders decision making process (100, 101).
- While information superiority may be necessary in the context of 'information-in-warfare', the strengths and vulnerabilities of new technologies for collection, processing and secure dissemination of information need to be recognised.
- Indirect IW impacts on the 'observe' part of an adversary's OODA loop. In many cases these could be platform-to-platform attacks, and may entail offensive and defensive EW, jamming in addition to psychological operations.
- Direct IW in the form of information attack (IA) impacts on the 'orient' part of the OODA loop. In this case, the decision maker would base actions on an analysis that is flawed, owing to the fact that the orientation step has been corrupted via the introduction of apparently credible, but incorrect information.
- There is a need to recognise that information attack is broader than activities concerned with attacking, and defending, technology dependent information infrastructure.
- IW would be the cornerstone of asymmetric warfare. Thus, for example, a threat of attack by hostile forces may be countered by an information 'attack' on an adversary's command and control system, air traffic control system or commercial power distribution system.
- Information attack in asymmetric engagements in future would require awareness and monitoring of activities in areas such as:
 - a) computer systems, including the Internet and world wide web
 - b) power generation and distribution systems,
 - c) industrial, financial and transportation systems,
 - d) adversary's information attack system
- New concepts on future conflicts, type of battlefield and capabilities need to be developed, since an adversary may not use forces in the traditional sense, but rather adopt an asymmetric approach via information attack.

(D). SUPPORT

6.21 Training

6.21.1. *Key features and Enabling Technology:*

- Increasing reliance on UAVs to perform reconnaissance, surveillance, combat and strike roles would have a significant impact on pilot and operator training. The operational and

training environments would now be one and the same, with no obvious difference between peacetime and war activities in a 'remote' or 'virtual' control center. Training regimes would have to take these factors into account. A capability edge would be provided by recognition of these issues, with HMI factors, information flow and use being key aspects of training programs.

- The move from cockpit to control center would entail more than a mere 'remote control' of the UAV. The pilot would not fly the aircraft using 'throttle and stick' in the traditional sense, but rather provide timely 'instructions' to carry out activities, based on an appreciation of the situation and the recognised air picture.
- Simulation would become more realistic with emphasis on VR and immersive technologies. There may be increased application of simulation for weapons training.

6.21.2. *Potential Impact and Implications for Australia*

- More effective personnel selection would be accomplished via advanced screening techniques, in both the cognitive and non-cognitive areas.
- A 'move' from cockpit (for manned aircraft) to a control centre (for UAVs) may have significant impact on operator/pilot requirements, and would have to be addressed well in advance of acquiring an UAV capability.
- Training regimes tailored to suit individual needs would be the norm, leading to training cost and time reductions to get an increased level of proficiency. The rapid rate of technological change also means that regular upgrading of knowledge and training levels would be required.
- Simulation may offer reduced training costs, owing for example to the requirement for less live firings in weapons training.
- Simulation would allow more effective distance training via distributed systems.
- While the increasing use of simulation may lead to reduced training costs, it would be essential to assess the veracity of the simulation and the effectiveness of the training.

6.22 Human Factors

6.22.1. *Key Features and Enabling Technology*

- There is increasing recognition that human factors technologies may offer enhancements in capability.
- Cognitive engineering may become a routine part of system design.
- Human and machine may be regarded as one integrated entity or system.
- Advances in helmet mounted displays (HMD), would involve insertion of mission and system information into the displays (102)
- In the shorter term humans may control systems via direct voice input (DVI), eye and head movement (102); while in the longer term control may be by direct EEG techniques.
- Virtual cockpit displays with no external views and all information on a helmet system may be developed (102)
- There would be increased automation of flight systems. A challenge is to have a seamless interface between machine and operator.

6.22.2. *Potential Impact and Implications for Australia*

- Human machine interaction and integration would be more effective, and lead to maximum system performance.

- Helmet mounted systems would support off-boresight weapons engagements (102)
- Virtual cockpit displays with no external view would provide protection against laser threats (102)
- EEG techniques may mean blending of human and machine as one functioning unit, with optimised performance and possessing 'think/act' capabilities.
- Automation can improve operator effectiveness, but improperly applied can reduce aircrew situational awareness and mission effectiveness (102)
- Capabilities such as this would have significant implications for training as well as aspects of cultural acceptance.
- Human factors and training are areas contribute to the maintenance of a 'capability edge' for Australia. The development of technologies related to these areas is ongoing, with some application in the near- to mid-terms, rather than long term.

6.23 Simulation

6.23.1. *Key Features and Enabling Technology*

- Ground truth data bases would provide total environmental characterisation, including visual, IR, terrain quality and atmosphere.
- Validated computer generated forces (CGF) could populate synthetic environments.
- Advanced distributed simulation architectures would enable interoperability.
- COTS components may reduce costs and increase flexibility and reconfigurability of simulators, which would be fully interoperable and deployable (82).
- Aircraft may incorporate on-board fast time simulation and include 'robot tacticians' (103).

6.23.2. *Potential Impact and Implications for Australia*

- Embedded simulation and stimulation would enable real systems to be networked with virtual and constructive simulations.
- Simulation would enable collective training within integrated 'synthetic environments' consisting of constructive, virtual, live (embedded in 'real' equipment) and C4I simulations connected in a seamless manner. This would add to the value of exercises, particularly when applied prior to and during activities.
- Simulation used to evaluate new systems in synthetic environments as part of the acquisition process would lead to better capability specification and system definition, thus providing overall cost savings and reduced timescales for the introduction of new capabilities (82).
- Simulation would allow "what if" questions to be answered with greater confidence in the context of operational planning and effectiveness.
- Computer generated forces (CGF) would allow timely mission rehearsal in more realistic scenarios. Deployability and embedded simulators would allow mission rehearsal while in transit (82).
- In the near term, on board fast-time simulation could be used to simulate full missile flyout to increase WVR and BVR air-to-air missile effectiveness, while in the longer term robotic tactical assistants could assist aircrew with selection of air combat tactics (103).

6.24 Logistics and Maintenance

6.24.1. Key Features and Enabling Technology:

- Advanced HUMS, enabled by increases in computing power and the application of AI expertise, would lead to fusion of information from a variety of monitoring sensors (90).
- There may be improved models to predict structural degradation in engine components for fatigue life prediction.
- Smart materials incorporating self-monitoring and self-healing capabilities could be used in platform structures.

6.24.2. Potential Impact and Implications for Australia:

- The advanced HUMS would lead to greater safety via earlier detection of degraded components and airframe performance. This would lead to overall better usage and reduced cost of component replacements, and is more likely in the near to mid term.
- Improved predictive models would lead to a retirement for cause rather than a management for safe life approach, for failure critical components (88).
- Increasing emphasis on condition based maintenance would mean the development of appropriate strategies to manage and interpret data from condition monitoring systems.
- Platform self monitoring capability offers greater assurance and the adoption of a 'replacement-for-cause' philosophy, while a self-healing capability offers increased mission capability and survivability, and greater platform availability.

7. Air Force Planning Outcomes: Some Implications and Issues

7.1 Command and Control

7.1.1. The concept of centralised command but decentralised control, rather than the centralised C2 of a hierarchical structure as accepted in current doctrine, may become critical in the future. While emerging information technology would allow rapid transfer and assessment of data and information, any 'speed' advantage may be lost owing to the cumbersome nature of a 'centralised C2 loop', leading to slow responsiveness. As a result, the potential shortening of the OODA loop provided by advances in technology may not be fully realised. Thus doctrine may develop to provide a command *or* control, or perhaps, a command and *coordination* function.

7.1.2. Under traditional hierarchical command structures, real time information availability may tempt higher commanders to become involved in the 'micromanagement' of Air Force activities at lower levels. However, such a 'skip echelon' phenomenon may prove to be counter productive. Thus, 'flatter', networked command structures may be adopted to take advantage of timeliness and rapid availability of information afforded by advances in technology.

7.1.3. Concepts of network centric warfare (NCW) may become more established. Such concepts incorporate grids comprising information, sensor and engagement functions. NCW concepts are based on the notion that networked nodes (e.g. sensors, weapons, platforms) offer greater capability than the sum of the nodes operating in isolation⁹. This

⁹ A statement to this effect is contained in Metcalfe's Law: "the power (value) of a network increases as the square of the number of nodes in the network" (104).

facilitates the integration and synchronisation of forces to enable the execution of time-critical missions (104).

7.2 Operations

- 7.2.1. The impact of emerging technologies on Air Force operations may be far reaching. Aircraft would be faster (including supersonic and hypersonic), stealthier and include human factors as a key element in their designs.
- 7.2.2. Information from on- and off-board sensors may be fused to provide battlespace situation awareness, with real-time updates.
- 7.2.3. UAVs present new operational challenges, while missiles would be faster, and have greater stand-off capabilities and explosive power.
- 7.2.4. In the longer term, Air Force activities may be carried out in both space and air environments. This would include combat in addition to surveillance and communications activities.

7.3 Simulation and Training

- 7.3.1. Use of simulation for training would become more realistic in that the training and operating environments may become one and the same. A UAV operator in a virtual environment may use the same environment for training but with computer generated 'training scenarios' taking the place of actual UAV operations. The switch from 'simulation' to real operations would be more seamless.
- 7.3.2. Likewise, use of simulation at higher levels means that operations and training become indistinguishable, from the point of view of process and interactions between humans and humans and machines. This may influence AF's approach to pilot, crew and mission controller training, and include novel issues regarding human factors.
- 7.3.3. Packages provided on an 'as-needs' basis would have implications for training. Software developments would impact on the knowledge worker, in that the latter may become redundant. This would impact on training levels and techniques, whereby regular, modular, short courses could be attended throughout ones career, rather than undergoing an initial long 'degree-type' course.
- 7.3.4. Distributed interactive simulation would enable interactive training at all levels and at remote locations.

7.4 Capability and Logistics

- 7.4.1. High rate of change in some technologies (IT, computing, communications) means that capability planning has to become evolutionary, rather than providing fixed specified requirements from the start. Thus, planners may have to adopt new strategies for capability development, since often the mean time between strategic decision making may be greater than technological advances impacting on the decision.
- 7.4.2. Better logistics tracking systems and automated inventory control would lead to a 'just-in-time' rather than traditional 'just-in-case' stockholding and logistics philosophy, and overall cost savings.

7.5 Acquisition

- 7.5.1. It is widely recognised that cost is now an independent variable in all defence acquisitions planning, and tends to drive interest in commercial technologies, processes and products. However, attention should not be focused solely on initial acquisition cost,

but also on overall life cycle cost. This latter emphasis is driven by the fact that 60 - 70% of most weapons systems costs are incurred subsequent to initial deployment of the system (105).

7.5.2. For any system, capability and technology demonstrators (CTD) and advanced concept technology demonstrators (ACTD) would become part of the process to move technology rapidly into use. CTDs aim to identify key technologies that may be ready for transition to an 'actual' capability and to demonstrate their performance parameters. ACTDs are developed outside of formal acquisition constraints, such as cost, so that iterative changes may be easily made. The aim of the ACTD is to (a) understand the utility of a technical concept, (b) develop concepts of operations and doctrine to make best use of a new technology, and (c) provide an operational capability to the user for evaluation. Key outcomes are: greater certainty regarding the capability provided by the technology, reduced risk and quicker transition from novel idea to actual capability; thus providing a sound basis for acquisition decisions (106).

7.5.3. Since future major procurements may have to last longer, accurate life cycle costing becomes more critical. Thus, life cycle cost models would have to include operational support elements like training, expendables, depot maintenance and mission personnel, all in the context of rapidly developing technologies in most relevant fields, but particularly in areas of computer hardware and software.

8. Conclusion

8.1 Impact of Emerging Technology on Concept Developments

8.1.1. Concept developments will be influenced by many factors, including technology advances. Examples of technologies with potential to significantly impact on concept developments are:

- laser weapons offering essentially 'zero-time-of-flight' to target
- information operations, where countermeasures will concentrate on the information processing and fusion 'end' of the system rather than at the sensor 'end' of the system
- information warfare (IW) may have implications for operations and countermeasures, in particular for the development of asymmetric warfare concepts
- communication and computing systems, particularly in the areas of broad band communication and artificial intelligence, may lead to advances in network centric warfare (NCW) concepts
- delivery systems capable of very high speeds and greater stand-off ranges
- low cost, miniaturised systems to encourage a shift in thinking from 'few high cost to numerous low cost' systems, with greater redundancy
- non-lethal weapons, such as those based on EPM, lasers and other 'tunable' systems.

8.2 Outcomes

8.2.1. The main aim of this study is to better inform Air Force planning in the context of a comprehensive 'futures' methodology. It should be understood that potential impacts of technologies' mentioned here should be used to initiate rather than complete discussion on future air force planning activities.

8.2.2. However, technology developments continue unabated, at rates determined by a number of drivers, and with unforeseen developments or breakthroughs always possible. Such developments give rise to technology based 'wild cards' in the *Air Force 2025* study (20). These, in combination with other factors, are used to create alternate future worlds. Examples of technology based wild cards are: computer-human nerve interface microprocessor; genetics breakthroughs yielding cheap and abundant foods; information warfare attack on economic assets; micro-electromechanical systems; artificial intelligence and 'new-wave' physics.

8.2.3. Thus, technological developments and their potential impacts should be revisited every few years in order to determine trends and to assess the robustness of the futures methodologies being applied. It is worth noting that the alternate futures derived by air force in the context of futures planning may have multiple future operating environments, while any future operating environment can occur in more than one alternate future (20).

8.2.4. Potential impacts of advances in NBC technologies are not addressed in this study, since it may be more appropriate to consider them in a broader context than air force activities alone.

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Appendix A: Acronyms and Abbreviations

ABL	Airborne Laser
ACTD	Advanced Concept Technology Demonstration
AEW&C	Airborne Early Warning and Control
AI	Artificial Intelligence
Al	Aluminium (element)
As	Arsenic (element)
ATM	Asynchronous Transfer Mode
ATR	Automatic Tracking Radar
BVR	Beyond Visual Range
BW	Biological Warfare
C2	Command and Control
C3I	Command, Control, Communication and Intelligence
C4I	Command, Control, Communication, Computing and Intelligence
CBM	Condition Based Maintenance
CBR	Computer Based Reasoning
CBW	Chemical and Biological weapons
Cd	Cadmium (element)
CGF	Computer Generated Forces
COIL	Chemical Oxygen Iodine Lasers
COTS	Commercial Off the Shelf
CTD	Capability and Technology Demonstrator
DARPA	Defense Advanced Research Projects Agency (US)
DBS	Direct Broadcast Satellite
DPSLL	Diode Pumped Solid State Lasers
ECCM	Electronic Counter Counter Measure (also known as Electronic Protection (EP))
ECM	Electronic Counter Measure (also known as Electronic Attack (EA))
EEG	Electroencephalograph
EMP	Electromagnetic Pulse
EO	Electro-Optic
EW	Electronic Warfare
FLIR	Forward Looking Infra Red
FLOPS	Floating Operations per Second
FPA	Focal Plane Array

Ga	Gallium (element)
GPS	Global Positioning System
GW	Gigawatt
HF	High Frequency
Hg	Mercury (element)
HMI	Human Machine Interaction
HPM	High Power Microwave
HUMS	Health and Usage Monitoring System
IFF	Identification Friend or Foe
In	Indium (element)
IR	Infra Red
IRCM	Infra Red Counter Measures
IRST	Infra Red Search and Track
IT	Information Technology
JDAM	Joint Direct Attack Munition
JSF	Joint Strike Fighter
kW	kilowatt
LEO	Low Earth Orbit
LPI	Low Probability of Intercept
LWIR	Long Wave Infra Red
MEMS	Microelectromechanical System
MIPS	Millions of Instructions per Second
mm	millimetre
MMI	Man Machine Interface
MMIC	Monolithic Microwave Integrated Circuit
MTI	Moving Target Indicator
MW	Megawatt
NASA	National Aeronautics and Space Administration (US)
NBC	Nuclear, Biological and Chemical
NCW	Network Centric Warfare
NDE	Non-Destructive Evaluation
NLO	Non Linear Optics
OODA	Observe Orient Decide Act
OTH	Over the Horizon
PGM	Precision Guided Munition
Pt	Platinum (element)
RF	Radio Frequency

RMA	Revolution in Military Affairs
SAR	Synthetic Aperture Radar
Sb	Antinomy (element)
Se	Selenium (element)
SEAD	Suppression of Enemy Air Defences
Si	Silicon (element)
SSTO	Single Stage to Orbit
Te	Tellurium (element)
TMD	Theatre Missile Defence
UAV	Uninhabited Air Vehicle
UCAV	Uninhabited Combat Air Vehicle
UHF	Ultra High Frequency
USAF	United States Air Force
UWB	Ultra Wide Band
VHF	Very High Frequency
VR	Virtual Reality
W	Watt
WVR	Within Visual Range
Zn	Zinc (element)

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on Future Air Capabilities**

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Intelligence Program

DGSTA Defence Intelligence Organisation
Manager, Information Centre, Defence Intelligence Organisation

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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION DOCUMENT CONTROL DATA		1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)		
2. TITLE The Impact of Emerging Technologies on Future Air Capabilities		3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)		
4. AUTHOR(S) Jimmy Ennett		5. CORPORATE AUTHOR Aeronautical and Maritime Research Laboratory PO Box 4331 Melbourne Vic 3001 Australia		
6a. DSTO NUMBER DSTO-GD-0186	6b. AR NUMBER AR-010-594	6c. TYPE OF REPORT General Document	7. DOCUMENT DATE December 1999	
8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR AFHQ	11. NO. OF PAGES 56	12. NO. OF REFERENCES 106
13. DOWNGRADING/DELIMITING INSTRUCTIONS			14. RELEASE AUTHORITY First Assistant Secretary Science Policy	
15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT <i>Approved for public release</i>				
OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, SALISBURY, SA 5108				
16. DELIBERATE ANNOUNCEMENT No Limitations				
17. CASUAL ANNOUNCEMENT Yes				
18. DEFTEST DESCRIPTORS Air capabilities, Technology developments				
19. ABSTRACT This study aims to assess technology developments to 2025, and how they may impact on future air capabilities, in order to better inform Air Force long range planning activities. A number of US studies address similar issues; with one assessing the impact in the context of an 'alternate futures' approach and the development of a value model. The generic Air Force capabilities of Awareness, Reach, Power and Support are used in this study to assess potential impacts of technological developments.				